Infra-free Life (IFL)-Proposal for a spin-off technology from aerospace into building industry

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[Abstract] This paper is focused on the development and implementation of a new type of infrastructural system within our building industry. A habitat that utilizes an IF system does not depend on any infrastructure and can be easily built/deployed anytime anywhere. This idea takes the concept of portable structures one step further. Nascent technologies from pioneering industries offer ideas, life support system concepts, materials and manufacturing technologies to introduce IF building technology to the construction industry. This paper makes an introductory discussion of what we mean by architectural infrastructure and its evolution, the concept of infra-free and its key elements, objectives, methodology and projects. The design methodology/ schedule will define IF research outcome that provides the linkage of design responses to requirements unique to hostile and space environments, which could be useful or even essential if adapted, for more mainstream architecture/urbanism applications, limitations and opportunities that can be foreseen in this approach.

Nomenclature

IF	=	Infra-Free
MIT	=	Massachusetts Institute of Technology
ESA	=	European Space Agency
NASA	=	National Aeronautics and Space Administration
BAU	=	Business-as-usual
BEMS	=	Building-Environment Management System
HEMS	=	Housing Employment and Mobility Service

I. Introduction

A continuing majority of the world's population is choosing to live in geographical areas with centralized infrastructures that can most easily support human life. These include sewer, gas-water-electricity supply, waste disposal and transportation systems, all of which remain as the most important consumer of environmental resources such as building materials, fossil energy sources and water.

These fundamental infrastructures constitute the backbone of our developed economies; they have brought us economic prosperity and have aided in the development and sanitation of our societies; however, this has come at the cost of **framing our thinking and stifling further progress** in the area of 'building technology'. Today, our infrastructures are aged, of high cost, and have repeatedly shown a range of weaknesses in a variety of disaster situations culminating in the need to rethink them.

However, there are instances where humans has chosen not to follow this lifestyle pattern due to exploration, research, forced occupation, or the inability to meet physiological needs of survival due to loss of infrastructure following a natural disaster. Current ecological trends show a heightened number of disasters and a relative increase in their severity. These effects are showcased in a variety of recent disasters spanning the globe. The efforts resulting from hurricane Katrina in the U.S. and the Niigata earthquake in Japan show even our richest and most developed countries are vulnerable and not amply prepared or equipped for these types of disaster solutions.

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II. What is Infra-Free?

Infrastructure consists of interconnected elements that provide the framework for supporting the entire system we inhabit. They provide basic facilities, services and installations needed for the daily functioning of our communities. Today, we primarily rely on *centralized infrastructure* to organize and manage our complex systems of flow, movement, and exchange forging an obvious reliance on its constant supply.

Infra-Free (Infrastructure-free) is the concept of not having to rely on centralized infrastructure. It also embodies a new way of thinking about existing objects and technologies to enable us to be more *self-reliant*. With the current paradigm shift toward information-based technology, digital production and mobility we have an opportunity to expand toward an **infra-free architecture**. The research conducted through IF project seeks to integrate smart, technologically and biologically inspired, or other unconventional approaches to lead to aggressive improvements in the efficiency, versatility and safety of future architecture. The foundation of this multi-disciplinary project is research on smart materials and construction systems associated with micro-electronics, environment protection, sensing and real-time adaptation to system changes.

Infra-Free Life is the idealistic conclusion to this research. It answers all of our demands to be in touch, stay in touch, work and live from any destination without having to compromise our daily needs. It provides us new ways of working, living and relaxing as we transcend into a new lifestyle of being completely self-reliant. (Figure 1)

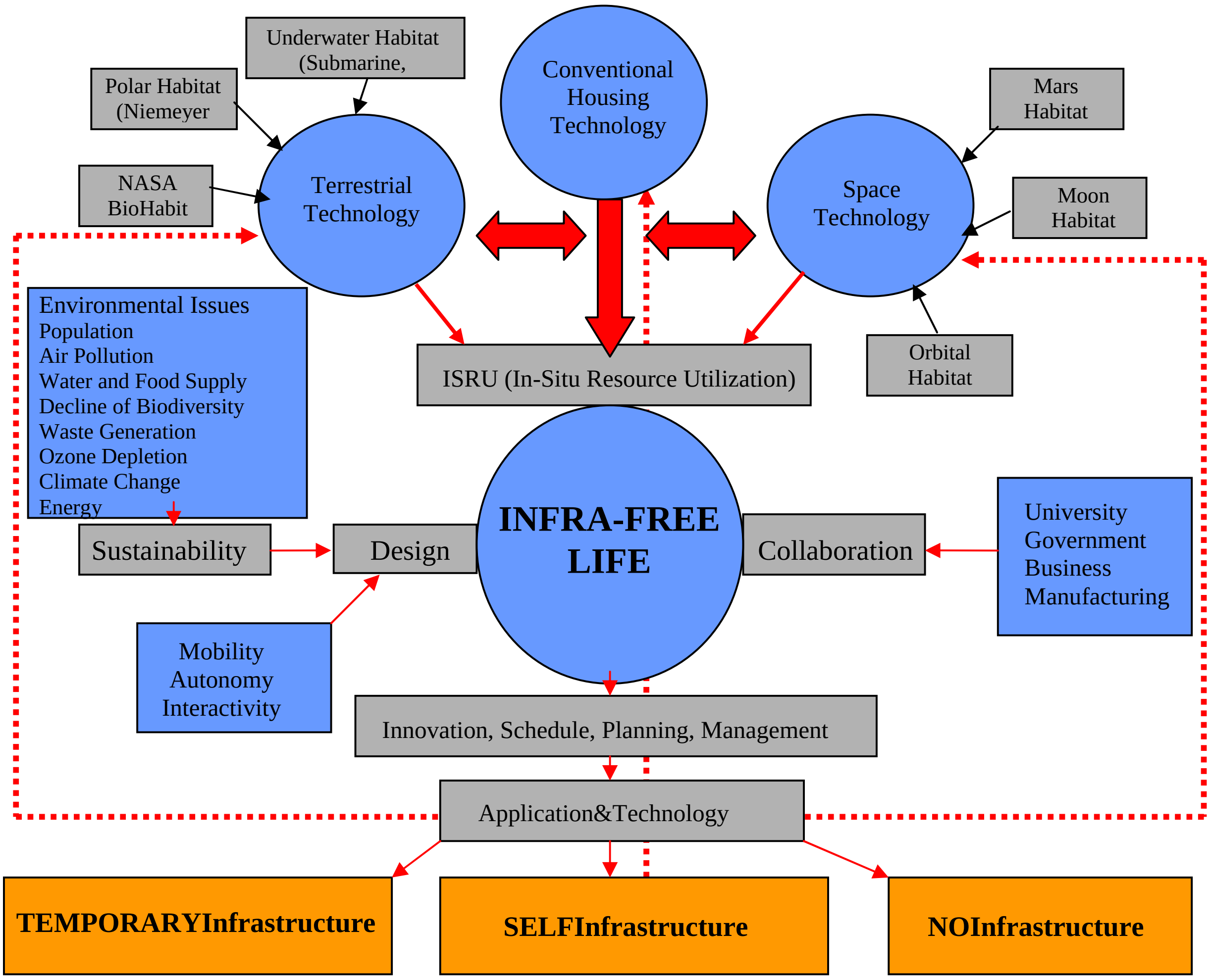

Figure 1: ***Definition of IFL Concept****- three different types of units are expected to be developed*

A. Previous Research

The main consumption of energy in the life cycle of a building usually occurs during the operation phase, i.e. the supply of electricity and other forms of energy for lightning, heating, cooling, ventilation and energy devices. Therefore most research has focused on reducing the energy consumption of these demands through the development of more efficient devices and alternative approaches to better use of natural light and ventilation. As a basis a database model, following table has been developed since 1990 for the Architectural Institute of Japan for sustainable building design[1]. We can see here that there is a need of focus on energy supply technologies to reduce the environmental impact of supplying necessary energy requirements of buildings. (Figure 2)

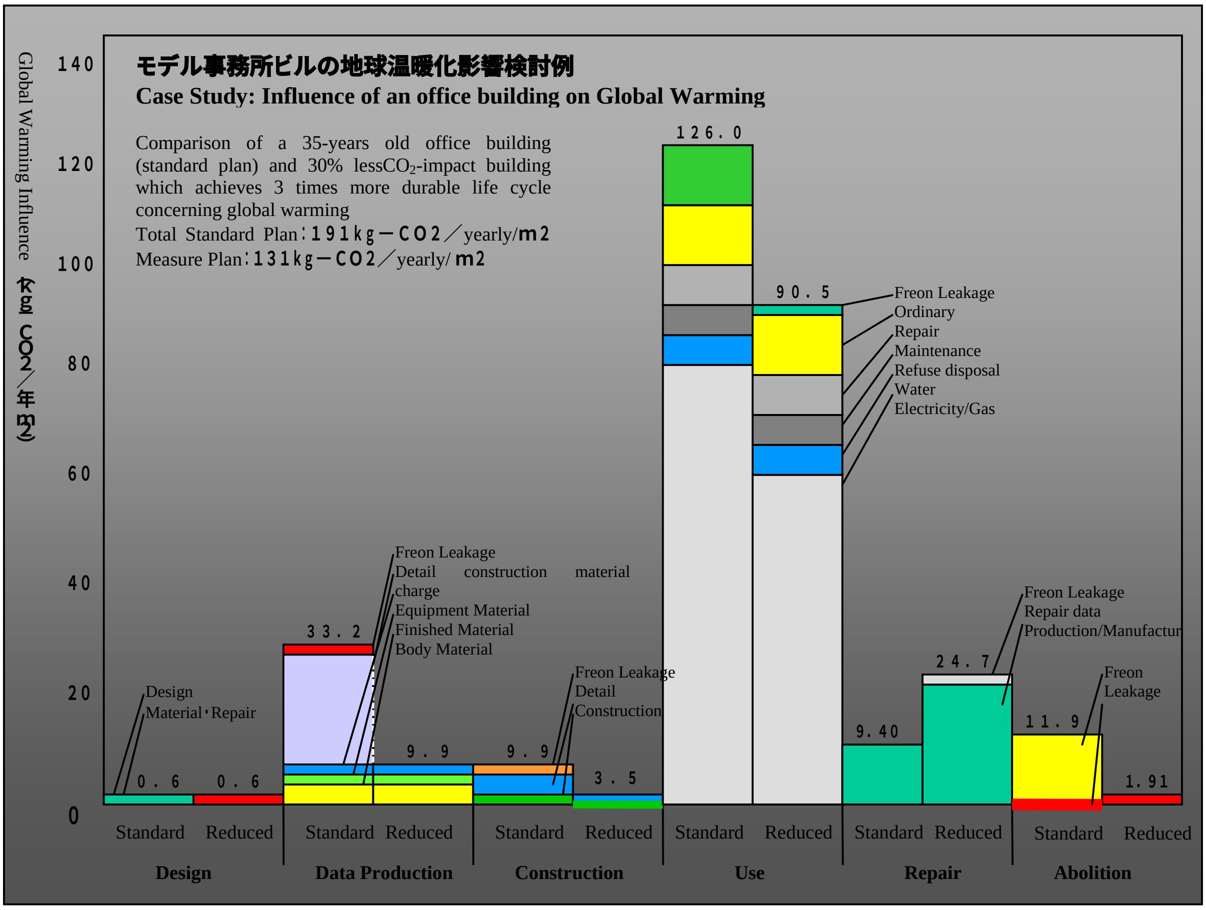

Figure 2: ***LCA Model****- Influence of an office building on Global Warming (Ikaga et.al, Ref.1)*

B. Research Objectives

The primary objective of IF is to **reduce the dependency on infrastructure** through the synergy of technology and nature. Thus, the task at hand, is rethinking the limitations and static framework of our current systems.

- IF strives to improve human life sand safety through:
  - ➢ Rethinking a safe/efficient alternative to current disaster relief solutions,
  - ➢ Providing an adequate supply of key infrastructures to improve the daily livelihood of the poor,
  - ➢ Providing an alternative to centralized infrastructural systems.
- IF also strives to rethink how we use technology:
  - ➢ To lessen our impact on the environment,
  - ➢ Both in our daily lives and during emergencies providing basic habitability (shelter, hygiene, climate, illumination, color and surface, décor, odor, noise, vibration, interior space layout, food) and long-term influences (family composition, safe storage, interpersonal dynamics, crisis management, motivation, communication, meal periods, privacy, mental care, off-duty functions)

C. Research Methodology

The aim of IF is the embodiment of all the defined key infrastructures (water, sanitation, electricity, etc.) working together to provide a safe and intelligent alternative to our current infrastructural reliant habitations. In principal, design is guided by a similar framework set forth by space habitation. (Figure 3)

Figure 3: MIR Space Station- *Space Stations are good examples regarding IF Concept (Ref: NASA)*

Burgeoned from the field of architecture and space design, IF is based on a cross-disciplinary approach of realizing its objectives. Initially, IF looks to simultaneously develop a technology database consisting of all potentially applicable technologies, and a design framework as a foundation for future IF projects. IF also has begun creating partnerships at the local level to help develop appropriate technologies, and local context within the design framework.

C. IFL Key elements

The infrastructures Key includes the most vital elements that our society provides for our survival and prosperity as listed below:

IFL WATER: safe drinkable water
IFL ENERGY: a reliable energy source
IFL SHELTER: a structurally sound place to inhabit
IFL SANITATION: safe removal of contaminated waste
IFL COMMUNICATIONS: continual exchange of information
IFL TRANSPORTATION: safe, accessible mobility
IFL FOOD: daily required vitamins and nutrients
IFL AIR: clean air
IFL EDUCATION: expansion of knowledge and social interaction
IFL RECYCLE: lessened environmental impact
IFL HYGIENE: a healthy level of cleanliness
IFL KIDS: tomorrow’s future vision

D. Research and Development Projects

Technology transfer is the process of developing practical applications for the results of scientific research. Through a multi-disciplinary approach, IF investigates nascent technologies from pioneering industries offering promising ideas that could be integrated as part of IF building technology applications under the following three groups and development schedule: (Figure 4)

1. NOinfra(structure)
Urban areas without or with inadequate amounts of infrastructure.
2. TEMPORARYinfra(structure)
Urban areas, where the infrastructure is lost because of natural disasters or other reasons.
3. SELFinfra(structure)
Urban areas, where the maintenance of infrastructure becomes a technological/economical problem.

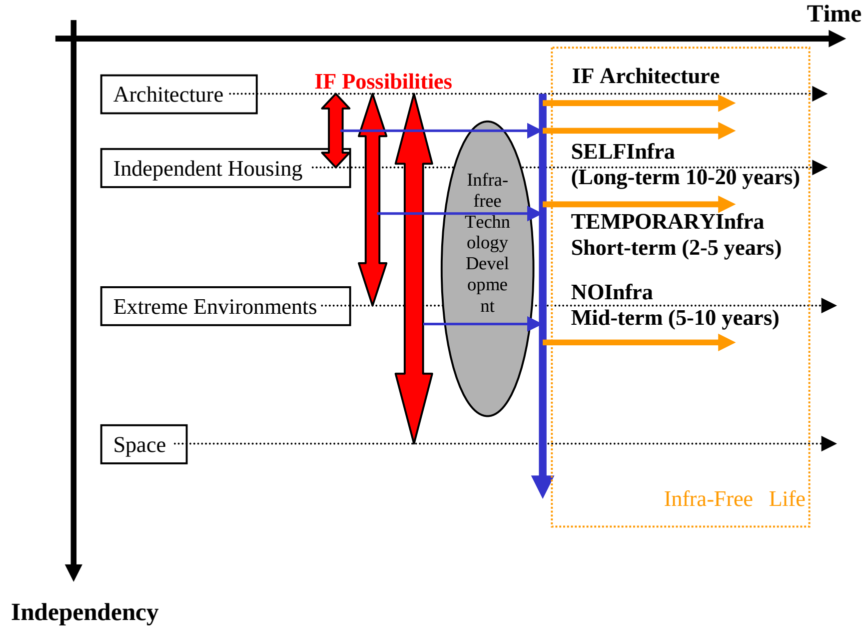

Figure 4: *IF Building Applications and time schedule*

1. NOInfra(structure)

Unstructured urbanization continues to grow throughout the developing world at an unprecedented rate creating peri-urban amoebas, which lack satisfactory hygiene and livelihood. These communities generally are forced to live without or with inadequate amounts of many of the basic infrastructural elements most of us take for granted.

<u>Case:</u> In exploring the case of NO-Infrastructure, it is important to do so within the context of global trends. As our world's population continues to urbanize over the next two decades 95% of urban population growth will take place in developing and least developed countries. Current trends show the majority of this hyper-growth will be *unstructured* and come in the form of *peri-urban slums*. These areas are characterized by a lack of access to potable water, access to sanitation, sufficient space, durability of structure, and security of tenure (legal right to settle there).

Currently, there are approximately 1 billion people in the world living without one of the above mentioned characteristics. Moreover, 20% of these households are in extremely poor condition meaning they *lack three or more* of the above mentioned characteristics.

NOInfra looks to address the current situation with two dynamics: upgrading existing slums and planning alternatives to prevent slums of future. Working with communities and municipal governments, IF will engage in a relationship-based process to help generate unique solutions to coup with such growth and conditions through collaboration, education and construction. Initially, the IF project intends to utilize a database of appropriate technologies, and a framework for structured incremental improvements of existing poor serviced areas. The mobilization of both community and local governments in the design and implementation process is a necessity.

2. TEMPORARYinfra(structure)

In the emergency period following a disaster, there is an immediate need for shelter. An emergency shelter should be self-reliant, sustain life, offer security, be accessible, include a water supply and sanitation system, as well as food and health provisions. Treatment of such facility should be temporary, prior to rehabilitation and re-housing.

In case of Japan, the Tokyo Metropolitan Government issued a new Earthquake report in which it predicted that only 4,700 people would be killed if a 7.3M earthquake should hit Tokyo. The same plan predicts the number of refuges as 4,075,700 people, $1/10^{th}$ of Tokyo Metropolitan population[2]. The evacuation plan talks about the locations of refugee camps but does not provide any information on how the basic needs of the refuges will be supplied.

Case: Natural hazards such as earthquakes, floods, and drought cause tens of thousands of deaths, hundreds of thousands of injuries, and billions of dollars in economic losses each year around the world. Resulting in several billions of dollars in humanitarian assistance, emergency loans, and development aid expended annually. Over the last decade, there has been a steady increase of awareness in the need to facilitate an increased level of mitigation before a disaster strikes.

TEMPORARYInfra focuses on the initial impact of natural hazards is a particular concern with respect to shelter and infrastructure. The loss of these elements can cause a significant disruption of socio-economic life of communities leading to extended loss of life and property. A variety of sophisticated technologies have been developed in regards to forecasting, warning and monitoring, computerized systems of vulnerability and risk assessment, and satellite and remote sensing. These tools have lead to the identification and mapping of vulnerable areas and buildings relative to their geography, structure soundness, density (accessibility), etc. The results, on the other hand, under post-disaster relief and rehabilitation have continued to show a continual vulnerability especially amongst the poorer social classes, and a real societal unawareness of management culminating in a still ever-present danger of disasters. These efforts to reduce the risks of natural hazards remain largely uncoordinated across different hazard types and do not necessarily focus on areas at highest risk of disaster.

3. SELFinfra(structure)

As our society continues to mobilize, and our demands grow our reliance on centralized infrastructure seems antiquated and undesirable. Our ever-increasing need to be in touch, stay in touch, and telecommunicate from anywhere at anytime has driven progressions in technology forward in support of a new self-reliant nomadic way of life.

Case: Current lifestyles and patterns of societal development are unsustainable, impractical, and inappropriate when considered in the broad context of providing safe and equitable living environments for the rapidly increasing numbers of people inhabiting the Earth. There is an attractiveness to rediscover the distinction between urban and rural life especially in the sense of one's surrounding environment. Increasing the capability of a self-sufficient lifestyle with farming, DIY and self-help technologies, and decreasing the need for centralized infrastructures and services, could begin to offer alternative solutions to restoring a more sustainable lifestyle. *IF Life is an attempt to begin to reverse current trends and embodies new ways of working, living and relaxing; leading individuals into a new lifestyle of being completely self-reliant.*

In case of Japan; supply, maintenance, and economics of centralized infrastructure have become a major concern in suburbs where the density of the demand is low, and many rural areas which are currently not equipped. According to official demographic data, Japanese population will reach its peak in 2006 and then, will decrease to 100 million in 2050; dropping 17% in 50 years.[3] 220 Japanese small cities (not towns or villages) with fewer than 50,000 populations have experienced a decrease in population since 1994 due to people preferring to live and work in larger cities for convenience. The depopulating communities could benefit by introducing self-help production technologies.

SELFInfra suggests a completely different view towards revitalization of Japanese suburbs. If certain population limits are reached, Japanese officials cannot offer certain public services (like post delivery etc.) or certain infrastructures because of high cost and low return. To create the economy and society described here, the following three strategies will be adopted:

- create a virtuous cycle of rising productivity and growing income,
- take maximum advantage of globalization and information technologies,
- create systems to provide public values as selected by citizenry.

These conditions require long-term, comprehensive strategies that maximize and enhance the productive capacity of local ecosystems to produce food and energy, that recycle wastes and protect and improve water resources together with other necessary infrastructures, and that encourage resource-conserving modes of transportation, communication and life-style.

As an example to revitalize suburbs, Wade (1997) points out that, city governments have spent millions of dollars on efforts at removing slums instead of assisting people with attempts to improve their communities[4]. In most cases, infrastructures also use the most of assigned budget and there is just a little left for the actual needs.

By removing the dependence on infrastructure, self-production technologies in suburbs might find a new direction in developing more effective units for the improvement of their own society- from farmer to home builders, IF LIFE might offer new solutions, if essential technologies are improved or costs of existing technologies are reduced and financially supported by the government.

4. IFL Dichotomy

"Lifeline" is the daily life we experience and expect to have. Unexpected happenings could change our life-circulation and may have physiological, social and economical effects. In all three cases; lost and non-existence of infrastructure causes not only physical but also physiological and economical problems.

Everyday and Emergency- are usually thought of independently representing two completely separate environments and sets of rules. IF project seeks to blend these two worlds and associates everyday objects with possible transformations into essential objects wherein an emergency arises; oppositely, emergency objects tend to have little necessity in everyday life; thus, every object and concept developed by this project can be thought of as being useful and adaptable in either situation. In this sense, IFL will focus on following two key infrastructures: shelter and energy.

III. IFL Shelters

A shelter should sustain life, it should be accessible, have a water supply and sanitation system, and access to food and health provision. It is an immediate need in an emergency and should be treated as temporary, prior to rehabilitation and re-housing. Certain general design attributes are important in the functioning of such a temporary shelter: affordable, storable, easy to manufacture, reusable/recyclable/repurposable, easily transportable, easy to erect, incorporates local materials and conditions, usable in extreme conditions, and amendable to infrastructure connections[5].

A. Mobility

Portable architecture was the first kind of architecture man made and inhabited. Over millions of years, it changed, evolved and was rejected in favor of "permanent" buildings. Today architecture and permanence are treated as synonyms. We value solid buildings especially in the era of the 20th century - Permanence represents strength, longevity, etc.

Wikipedia Encyclopedia defines the word 'Mobility' as "*a movement that involves changing the position of oneself or an object*"[6]. IF project defines 'mobility' as "**capability of moving or changing quickly from one state or condition to another**" using two key statements:

- Shelter/Communication: A mobile object, which can be carried at all times, that provides infra-free shelter and/or communication in case of any type of disaster.
- Transportation: The ability to move from a 'disaster zone' to a 'safe zone' without the reliance of infrastructural transportation services.

In 1960s, Archigram proposed ideas like 'plug-in city' and 'walking city', suggesting an image of a flexible city with detachable urban functions. Prof. Kengo Kuma (2005) discusses that "cellular phones" have gone a long way toward actually making this vision a reality[7].

B. Embryonic Architecture

In mobile architecture we may categorize all systems under either 'deployed' or 'prefabricated' structures. Deployed structures can be divided into 6 main systems: Flat packed, pantograph, membrane systems, pneumatics, tensegrity structures and pods/capsules[8].

One good example, TransHab is the first endoskeletal space habitat, consisting of a dual system: a light, reconfigurable central structure and a deployable pressure shell. The shell is so resilient because it is made of several layers, each with its own purpose. Principal among these is the restraint layer, which is interwoven to distribute tremendous loads evenly and efficiently around its torus, much in the same way as the reeds in a round basket are woven to spread weight and give the basket strength. Each strap is made of Kevlar ®, an aramid-fiber material, which has a very high strength-to-weight ratio and great impact resistance, and is often used today in the making of bulletproof vests. Woven together into the vehicle's main shell, these straps when inflated form a system that is capable of withstanding up to 4 atmospheres of pressure differential (over 54 psi) between interior and exterior[9].

Infra-free project aims to add an additional category to the previous classification and proposes to understand more about nature-driven forces and their application possibility to architecture by taking the concept of an embryo- a cell in the earliest stage of development- and to develop units that can breed and grow on site. Examples of similar concepts are: Howe& Colombano (2004) propose self constructing/self-reconfiguring modular construction systems[10]. Brewin and Crawford (2004) propose a rapidly deployable hardened shelter that requires only water and air for construction- the concrete canvas- can be deployed by a person without training in under 40 minutes and is ready to use in 12 hours[11] (Figure 5). But we have to mention that Concrete Canvas would be hard to take down again. Mitchell (2005) proposes a method to grow homes from natural seeds. In his project *'Fab Tree Hab'*, he proposes a self-growing/recycling home from a local biota & fauna graft living structure[12] (Figure 6).

Figure 5: Concrete Canvas- *a rapidly deployable concrete shelter (Brewin and Crawford, Ref.11)*

Figure 6: Fab Tree Hab *A self growing and recycling home concept (Mitchell, Ref. 12)*

German Architect Wolf Hilbertz with his project Autopia Ampere proposes growing cities in the sea through an application of "mineral accretion". The general concept uses CO2 absorbed in sea water through electrochemical reactions which will draw the minerals out (mineral accretion) to create limestone[13] (Figure 7).

Figure 7: Hibertz's Autopia Ampere *The natural flow of mineral accretion creates material of building(Hibertz, Ref. 13)*

Such projects enable a completely different insight into the development of buildings by eliminating the conventional construction phases and management philosophy. Together with Japanese counterparts, we aim to find the synergy between these two concepts: technology- and nature-driven systems, in order to develop lighter and more mobile units according to the criteria mentioned in previous section. The challenges to develop a single-cell like unit and allow self-growth through time might radically change the definition, rules and tools of manufacturing.

C. Space Architecture

Recent advances in materials technology have improved the performance of capabilities of inflatable, flexible composite structures, which have increased their potential for use in numerous space applications. Space suits, which are comprised of flexible components, are good example of the successful use of inflatable composite structures in space. But future explorers on the Moon and Mars could be outfitted in lightweight, high-tech space suits, far more flexibility than the bulky suits that have been used earlier.

1. Spacesuits

Research is under way at MIT on a Bio-suit System that incorporates a suit designed to augment a person's biological skin by providing mechanical counter-pressure[14]. The 'epidermis' of such second skin could be applied in spray-on fashion in the form of an organic, biodegradable layer. Advances in fabrication and application of open cell foam- a type of foam where the cells will allow air to pass through them-, smart materials like advanced 'muscle wire' technologies and electrospinlacing- the use of electro-spinning to combine different fibers and coatings to form three dimensional shapes, like clothes.

Another research funded by NASA Institute of Advanced Concepts studies a 'chameleon suit'[15]. The name reflects the fact that walls of the suit change in response to variations in the environment or in the wearer's need for cooling. The ultimate goal of this concept is a symbiotic interaction of astronaut and spacesuit like that between human and nature in which the astronauts' waste carbon dioxide and water vapor are converted back into respirable oxygen in the suit walls using environmental energy sources.

This concept can be implemented to provide effective thermal control using emerging technologies that are expected to mature within less than 40 years, opening an evolutionary approach for the building industry.

2. Self-Healing Structures

Researchers have taken inspiration from human skin, which heals a cut by exposing blood to air, which congeals to form a protective scab, working like an autonomous system. A material that could enable spacecraft to automatically 'heal' punctures and leaks is being tested in simulated space conditions on Earth by researchers from the University of Bristol and ESA[16]. They came up with a similar idea for protecting spacecraft; fabricating a composite laminate material containing hundreds of hollow glass filaments 60 microns wide, each with an inner chamber of 30 microns in diameter. Half of the filaments are filled with an epoxy polymer or resin and the other half filled with a chemical agent that reacts with the polymer to form a very strong and hard substance. The glass filaments, which are cracked easily when the overall composite material is damaged, which causes both chemicals to leak out and rapidly plug the resulting crack or hole.

Glass-tube approaches could have certain limitations when we try to run them in the third dimension. Taking this idea one step further for a complete spacecraft or a building, we can integrate hollow vascular channels directly inside the building material. Such a 3D-network could act as blood vessels of human body, not only carrying material-repairing fluids but also report structural damage by alerting or as circulating coolants. The building skin will have an entire evolution through smart materials. There is still a decade that such technologies can find their way in a building but research and interest in both aerospace and building engineering can create profits and certain time-savings for both industries.

IV. IFL Energy

Space stations (like buildings) represent the largest kind of infrastructures in space. As they are used intensively over long periods of time, it is not surprising that they are also the largest power consumers in space. Due to the current mode of power generation by means of solar generators, the large collector surfaces are the dominant components of a station.

Since IF units will be operated over long periods of time, naturally the following question like space stations arises: *which energy sources are suitable?* In Earth orbit, the most practical source of power for the space station is sunlight. The Sun radiates $4x10^{23}$kW. If we could collect it all, the Sun's power output would be enough to supply the demands of 31,000 billion planet Earths. In fact, our planet intercepts only about a billionth of the Sun's total output, but even such a small fraction represents a large dose of power. Photovoltaic cells remain the most practical way to extract power from sunlight in space. NASA-Glenn Research Center developed the highly-refined photovoltaic (PV) technology that is being used on the ISS; mounted on eight-large, wing-like structures called solar arrays, each measuring 34m long and 11m wide. The arrays together contain a total of 262,400 solar cells and cover an area of 2,500 square meters. A computer-controlled gimbal rotates to keep the arrays tilted toward the Sun.

The spacecraft is in eclipse for up to 36 minutes of each 92-minute circuit around our planet. During the shadow phase the space station relies on banks of nickel-hydrogen rechargeable batteries to provide a continuous power source. Those batteries consist of thirty-eight cells connected in series and packaged together in an enclosure that monitors temperature and pressure. The unit is designed to allow simple removal and replacement. The batteries, which are recharged during the split phase of each orbit, are expected to last more than 5 years. Switching back and forth between solar-generated power and stored battery power was a challenge for designers of the station's power system. The entire electrical power supply has to be switched smoothly twice each orbit, distributing reliable glitch-free current flow to all outlets and devices. The result of this carefully managed process is 110kW of power available for all uses. After life support, battery charging and other power management uses take their share, 46kW of continuous electric power are left over for research work and science experiments[17].

That' is enough to run a small village of 50-55 houses.

ISS Power is a bit different from the electricity delivered to homes on Earth, though. Rather than familiar alternating current (AC) that courses through city power grids, ISS runs on direct current (DC) power. Electrical devices built for ISS are designed to use the station's 120-volt DC power, but devices from Earth such as portable CD players or electric razors must be adapted to this unusual power system.

The power management of an IF module, creating its energy from environmental sources and recycle-based life support systems has to make a choice between AC and DC for best performance. The regenerative operation in connection with the life support system can help the adaptation of existing technologies, ex. fuel cells, although they would not be relevant due to their high replenishment demand for fuel, if used alone. Life-support systems are good databases to achieve IF modules.

A. Future Energy Sources

Fossil fuels are a finite source. While the developments of renewable energy such as hydroelectricity, of nonrenewable energy such as nuclear power, and scientific advances have reduced the dependency on fossil fuels, demand has increased nonetheless. Renewable energy sources capture their energy from existing flows of energy, such as sun, wind, wave and flowing power, biological processes such as anaerobic digestion, biomass and geothermal heat flow.

As the first step of IF research, database of possible new/improved technologies and their integration into the building industry is the key of success.

1. Continuous Wind Energy

In a small-scale wind turbine, wind rotates the turbine that is spinning the generator to produce AC voltage. But because the wind speed is variable, the voltage is not continuous and may be too low to be stored in batteries or fed into the grid. Taking the space station as an example, if the AC current produced is converted to DC in the rectifier, it can be stored in what is generally a 12-volt battery. Since a battery cannot recharge on voltage that is lower than its output, a unique controller has to monitor the frequency of AC from the generator. Department of Electrical and Computer Engineering at the University of Alberta is working on such a device; if the voltage is too low to be rectified and sent through the system for storage, the controller directs a switch in the converter to stop the flow of electricity and pool it until the voltage is 12 volts. The switch in the converter opens and closes thousand times per second. This system can be applied where average wind speeds are less than 11mph; a 6-ft.-dia. Turbine could produce 24kWh a day. The standard U.S. household uses 35kWh a day. The addition of a simple inverter to change the battery's DC voltage to AC would enable homeowners selling surplus electricity to the grid. However, a clear site that wind can hit from any direction is a must.

2. Organic Solar Cells

When light strikes both organic solar cells and conventional silicon ones, photons are absorbed by a semiconductor material. The photons` energy causes previously stable electrons to become excited and move to the edge of the cell, where they come in contact with a metal, usually copper. This conductor draws the current to where it is needed. While silicon materials are based on inorganic elements, such as copper alloy, gallium and silicon-materials sometimes in short supply- organic solar cells are composed mainly of carbon, hydrogen and oxygen molecules. The Center for Organic Photonics and Electronics at the Georgia Institute of Technology paired a crystalline organic film called pentacene with C60, also known as 'buckyball'. In a 1sq.-cm cell they generated 3 milliwatts.

Organic solar cells can be applied to systems with low energy requirements in 2-3 years, and power laptops or cellular phones in 5-10 years. Although the science of manipulating organic cells just started; because they are light and flexible, they could be placed on any surfaces, even on a tent or clothing. Currently, organic solar cells reach efficiencies of 3 to 5 percent, but if plastic-backed organic cells can be mass-produced by the yard, all sort of surfaces can be converted into solar power harvesting collectors.

3. Electricity from organic waste

On a two-year trip to Mars, a crew of six humans will generate more than six tons of solids organic waste, which most of them are feces. Today, astronaut waste gets shipped back to Earth but for long-term exploration, recycle could be a solution because it holds resources that astronauts will need- drinking water, fertilizer and even the chance to create electricity.

A bacteria from the *Geobacteraceae* family called *Geobacter,* which likes to live in places where there is no oxygen and plenty of iron, have unexpected ability to move electrons into metal. That means that, under right conditions, they can process waste and generate electricity, which is also called a ‘microbial fuel cell’- they obtain their electrons not from hydrogen, instead, from organic waste. The bacteria at the heart of the device feed on the waste, and as part of their digestive process, they pull electrons from the waste material. *Geobacter* microbes and some other types, can be coaxed to deliver these electrons directly to a fuel cell electrode, which conducts them into a circuit- when they flow through it, they generate electricity.

Researchers at Pennsylvania State University (PST) developed an electricity generator fueled by sewage. Even better, the device breaks down the harmful organic matter as it generates electricity, the job of a sewage-treatment plant at the same time. Basically it harnesses the same way our body does to break the food we ate- but diverts electrons liberated in the reactions to produce electrical energy. (Figure 8)

If human waste can be used as power source, the combination with a interior-garden could eliminate the need for sewage. Introduction and improvement of this concept and integration into close-loop life support system can make our buildings more independent from the infrastructure around.

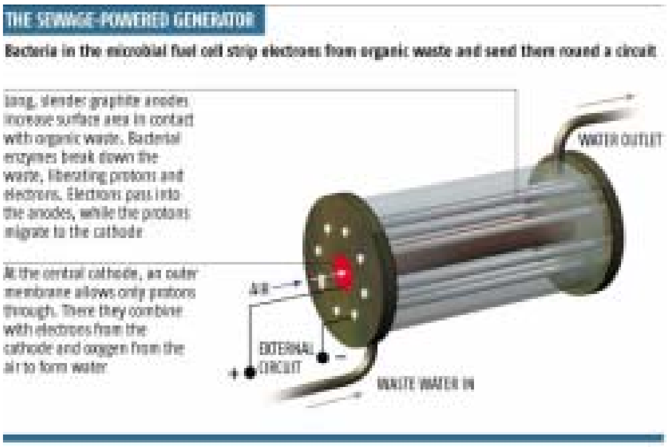

Figure 8: The sewage-powered generator, *a system where bacteria creates electricity from organic waste (Ref. PST)*

B. Simple technologies

Many solar applications are on the market in developing countries. Yet the market remains highly limited. Few current solar technologies can pass the test of being affordable, accessible and appropriate. They have mainly been designed, developed and manufactured in industrialized countries and then exported. As a result they simply cannot meet the needs of ordinary people, who continue using kerosene, candles or dry cell torches, at considerable cost to their budget, danger to their homes and health, and with a poor lightning result. Research in this field to target energy-saving, simple and affordable technologies offer new visions for IF research. Some of them are:

- *Solar lanterns:* High performance and power output, mobile (small and light), charged with a solar panel daytime; both price of lantern and solar panel does not exceed $100. Finance achieved through driving cost down factors while maintaining a robust and reliable product.
- *Pedal-powered generators:* The most efficient way to use the created power would be not to create electricity at all, but to power up simple home applications. The second most efficient way to use the power is to pedal a generator to electrically power TV, radio, floodlight etc. directly, with no battery. The least efficient way to use this power is to generate electricity and store it in a battery, then extracting it to some power device.
- *Ultraviolet (UV) Water Filters:* UV Filters are able to kill the majority of bacteria and viruses in the water which passes through them. However, they won't remove chemical pollutants from the water. Water−fed by pressure, pumps, or gravity−enters a long, curved pan. Ultraviolet light from an unshielded fluorescent fixture disinfects the water, and the now-clean water spills out into a holding tank for later use.

- *Solar Distiller:* The sun's energy heats water to the point of evaporation. As the water evaporates, water vapor rises, condensing on the glass surface for collection. This process removes impurities such as salts and heavy metals as well as eliminates microbiological organisms. The end result is water cleaner than the purest rainwater. It is a passive solar distiller that only needs sunshine to operate. There are no moving parts to wear out.

Space technologies, like simple technologies mentioned above, are by their very nature developed to work in extreme environments, relying on unusual combination of materials, and to have a long intervention-free operating life. Principal design requirements are: lightweight but nevertheless robust designs, maintenance-free operation, high-degree automation and energy autonomy. The fact that 'space habitats' have to support life in hostile environments by relying on leading-edge technologies means that the latter can be also a valuable source of innovation for the building sector here back on Earth.

V. The Infra-Free Building

The technology research effort of aggressive literature search and review to identify and evaluate published information on relevant technologies as well as follow up contacts with Japanese researchers and visits to different technology laboratories in the field to clarify and expand upon the published data and to obtain their perspectives on research trends and anticipated progress in their fields. In these contacts, we also have sought to understand the application and funding sources currently driving the most important lines of enabling research and to identify those areas where focused research activity specific to Japan's needs and IF concept application in particular was most likely to be required for successful development of the project.

The increase of energy consumption is recognized as one of the global risks in the century and the requirement for stable energy supply has become an emergent issue not only for Japan but also for all nations.

With the application of successful energy policies, the average Japanese person consumes 4282 watts of power per year[18]. (Data: 2002) This is far less than US (10,000 watts) and industrialized countries (7400 watts) average power consumption. Although the commercial and residential household sector has made progress in terms of energy efficiency of appliances, its energy demand are also increasing due to the increasing ownership of new appliances and the growing public demands to seek for more comfortable and convenient lifestyle. In order to deal with this trend, following collective measures have been launched:

- improving energy efficiency in machinery and equipment,
- improve the heat insulation performance in residential buildings,
- management of total energy demand through improving new energy technologies.

Our enabling technology research effort will be directed toward several broad technology thrusts that we have identified as central to the concept:

- Energy conversion and transport materials,
- Energy storage systems,
- Chemically active materials,
- System control and integration technologies.

A. Sustainability

The University of Tokyo and 4 Japanese Heavy Electric Machinery Companies formed a research initiative called 'Triple 50', which targets for 2030 to reduce the rate of dependence on fossil fuels from 80% (at 2000) to 50%, to increase self-sufficiency rate from 20% (at 2000) to 50%, and to increase the rate of energy utilization from 35% (at 2000) to 50%[19].(Figure 9) The total energy supply at 2030 should be reduced by 30% compared to 2000, and will be composed of 50% fossil fuel, 25% nuclear and 25% renewable sources. IF vision, similar to the concept of holonic energy systems composed of well-balanced distributed and concentrated power systems, will be one of the key major technological challenges which focuses on the reduction of energy consumption of civilian sector; creating a synergy between low-tech and other leading-edge technologies. (Figure 10)

	Industrial Sector	**Civilian Sector**	**Transport sector**	**Total**
2000	195	117	101	413
2030 (BAU)	188	136	101	425
2030 Triple 50	179	87	59	325

Figure 9: *Energy Consumption of different sectors in Japan (10^6kl-oe) (Shikazono, Ref.18)*

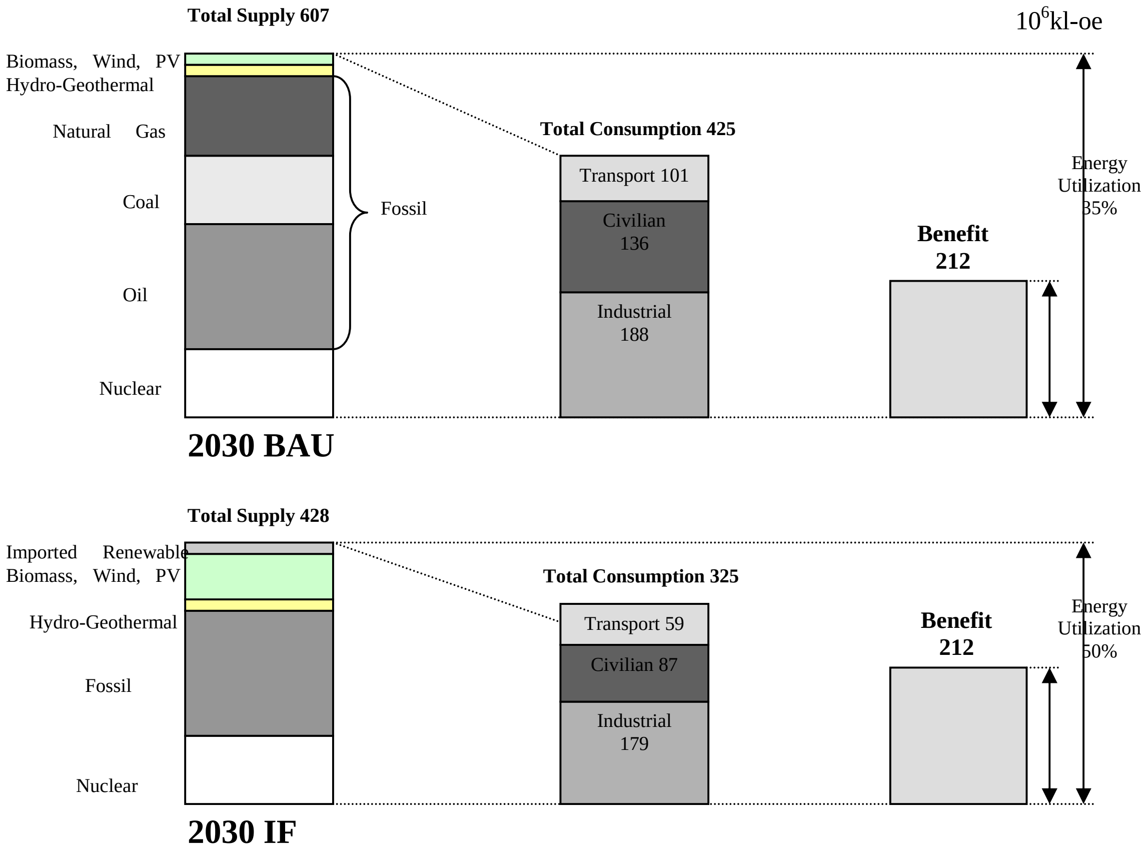

Figure 10: *Energy Supply-Consumption and Benefit Model*

The reduction in civilian sector can be achieved through simple technologies and design measures, which are already existing technologies and knowledge. Efficient lightning, use of heat pumps and insulation are important keywords to succeed. Space technologies can provide valuable information in all these cases- especially in insulation- NASA-developed radiant barrier technologies, in order to maintain a consistent temperature where ordinary insulation methods will not suffice. These are used both on spacecraft and spacesuits. (Figure 11)

Using conventional insulation, a spacesuit would have required 7-foot-thick protective layer. Two sheets of aluminum adhered together and tri-laminated to a thermal break to create a two-sided reflector, perforated with tiny holes that allow moisture to pass through could easily lower the amount of heat transferred into a home in summer and out of a home in winter. Furthermore, adaptation of space materials could increase the insulation quality of every home[20].

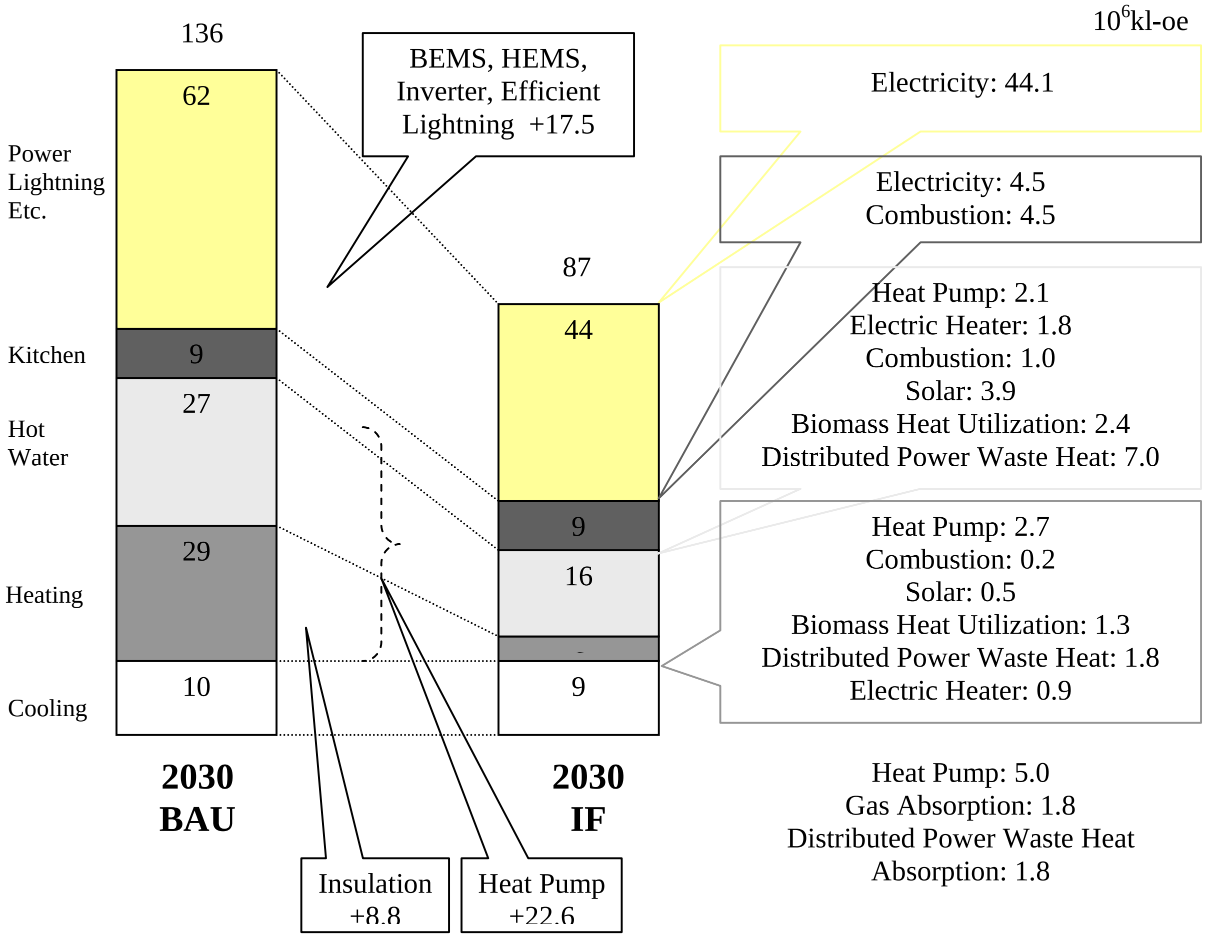

Figure 11: *Simple design measures to reduce energy consumption in civilian sector*

B. Cost Assumptions

In order to develop a unit that is independent from basic infrastructure like electricity, water, gas etc.; the concept should focus on '*where it would be built*' and '*how much it would cost*'. We already mentioned that in the first years, IF research will focus mostly on **NOInfra** (Slums, developing countries and extreme environments) and **TEMPORARYInfra** (After-disaster temporary housing) because people living in these geographies are in urgent need of basic infrastructural elements like clean water or electricity etc.

Although each unit will differ in detail depending on the geographical and cultural aspects of target region; an important aspect would be the cost of each unit, which has to be set at a level which is affordable on average incomes or is easy to be supported by different governmental organizations or NGOs. It should also offer people a healthy and comfortable living environment.

A basic study has been made to analyze how cheap a simple solar system could be developed. The challenge was just to use a **'single'** solar cell (75 Watt) because it's cheap and affordable, and easy to find in any country around the world; new or used. In this sense, an important discussion point was what electrical appliances inhabitants would need to run. Similar to a space station, to ensure enough comfort with the most affordable price; by the careful planning of interior elements and adaptation of energy saving features in each phase, the cost assumption of a simple system that covers the complete electricity need for one unit came out for less than $700. (Figure 12)

Appliances	Item	Power	Cost	Comments
Lightning	120VAC compact fluorescent(CF)	9W (room light) 6W (kitchen light)	$8 $8	VAC bulb cost is five times cheaper than VDC. High-efficient
	12VDC/120VAC Halogen light	20W (bedroom) *20W (outdoor-not always)*	$6 $6	Even the system is turned off for power saving, still light available for short time, halogen lights good for reading.
TV	13-inch color TV	54W (rated) Normally in normal use draws only 25W	$100	Communication and information technologies adapted even if there is no TV reception.
Computer	M.I.T. Project	10W	$100	Reference: MIT Media Lab $100 computer project
Radio	Hard-wired on/off system	5W	$10	No phantom load- if remote controlled system- device still uses energy even if stand-by case.
Total		**75W**	**$238**	
Future Needs	User defined energy-consuming appliances. Depending on geography, this could be any type of necessary infrastructural element, like water pump etc.			

Figure 12: *Interior Electrical Appliances and their power/cost performance for IF units*

One important aspect is the maintenance of the system. Each unit has to either maintenance-free or it should be easily maintained by users. Thus, it should be easy to build. DIY (Do-it-yourself) offers various possibilities to erect systems depending entirely on user-defined components, even used. Taking DIY as an example, following study worked on the system components, which would create the necessary infrastructure to use the power from a single solar cell efficiently. (Figure 13)

Component	Price	Description
Solar Panel	$97	DIY Solar Panel Kit , 75W
Battery Bank	$42(x4)	4 golf cart batteries, 6VDC, 200amp/hours. If wired in series and parallel, the output reaches up to 440amp/hours. This is more than enough for minimal loads inside the unit, giving the system time to charge up when user is away from home.
Inverter	$45	300W, it includes fuse on main power cable and overload shutdown.
Charge Controller	$40	Rated for 16 amps to provide room for adding more solar panels later.
Solar Panel Mount	$20	Necessary components for installation
Metering	$10	Digital multimeter, with LED to indicate full charged condition.
Sub-Total	**$380**	**DIY components**
Sub-Total	**$238**	**Interior Applications**
TOTAL	**$618**	

Figure 13: *System components for a DIY energy management concept*

It would be impossible to power a conventional home with a system of this size but this design shows that if we are conservative with the power use, realistic with user's expectations and investigate DIY concept for construction and self-maintenance purposes, each unit could be powered for a very affordable price. DIY is not the final solution for IF research; but one concept, which is of great importance. Various scenarios for energy management will be developed.

C. Schedule

Developing a design framework is the key element to succeed in IF research. This framework will inhabit key technologies to design pilot projects for each three keywords and create collaboration between local community members, governments, academics and professionals. The basic flow of the two-year research will be:

- Create a database of existing/on-going research/technology
- Evaluation of each technology through creating different scenarios for different environments
- Establishing life-cycle proposes by integrating different water and energy concepts and their total evaluation (Figure 14)
- Designing pilot projects for cost evaluation.

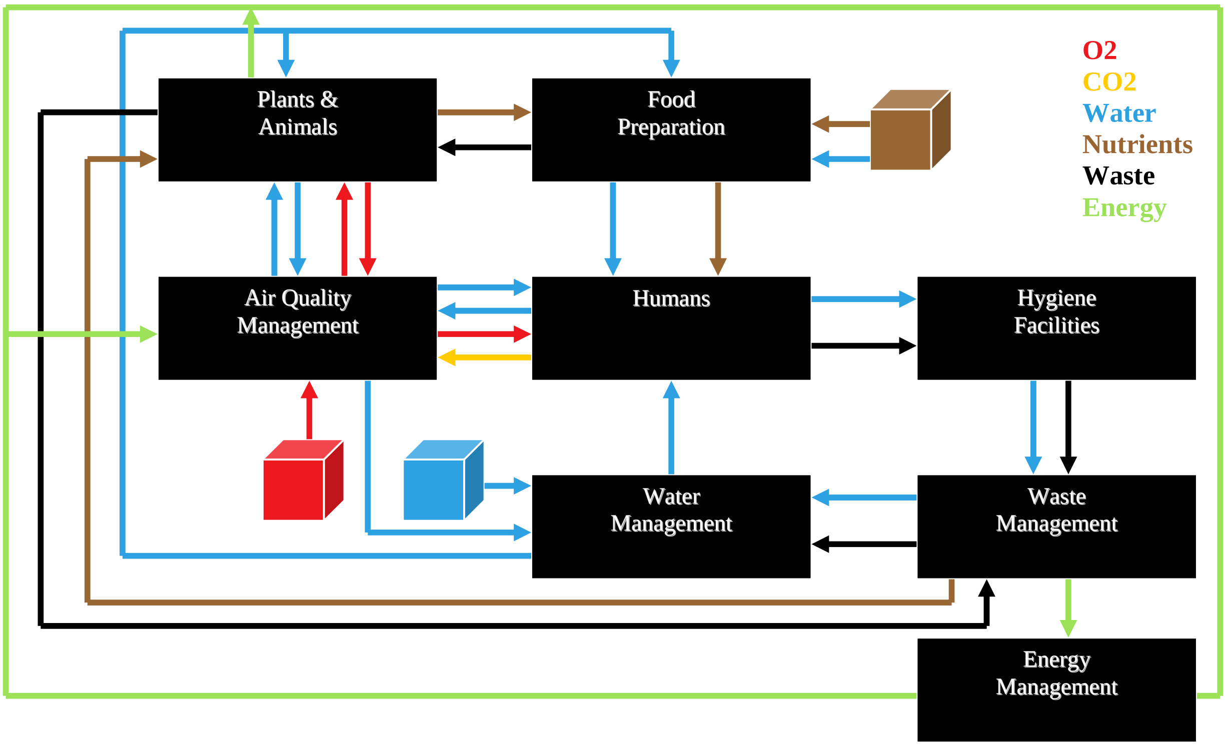

Figure 14: IF Building Energy and Water Management Concept-
the elimination of sewer through system integration

VI. Conclusion

As shown in the preceding technology concepts and discussions, possible implementations of the IF concept draws a wide range of emerging energy technologies spanning materials science, biology, chemistry and electronics. Many of the required capabilities are only beginning to be explored in university, industry and government research laboratories, and some must be considered speculative at present. As a result, data characterizing the technology that will enable the IF concept have not general been consolidated and organized for ready reference yet. However, a research effort to ascertain and understand the current status and future prospects of the required technology development efforts has been a major part of our study activity.

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