Infra-Free[®] (IF) Architecture System as the Method for Post- Disaster Shelter Model

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Currently, International Space Station (ISS) is capable to support 3 to 4 astronauts onboard for at least 6 months using an integrated life support system to support the need of crew onboard. Waste from daily life of the crew members are collected by waste recycle systems, electricity consumption depends on collecting solar energy, etc. though it likes the infrastructure we use on Earth, ISS can be comprehended nearly a self-reliant integrated architecture so far, this could be given an important hint for current architecture which is based on urban centralized infrastructure to support our daily lives but could be vulnerable in case of nature disasters. Comparatively, more and more economic activities and communications rely on the enormous urban central infrastructure to support our daily lives. Therefore, when in case of natural disasters, it may cut-out the infrastructure system temporarily or permanent. In order to solve this problem, we propose to design a temporary shelter, which is capable to work without depending on any existing infrastructure. We propose to use some closed-life-cycle or integrated technologies inspired by the possibilities of space and other emerging technologies into current daily architecture by using Infra-free[®] design framework; which proposes to integrate various life supporting infrastructural elements into one-closed system. We try to work on a scenario for post-disaster management housing as the method for solving the lifeline problems such as solid and liquid waste, energy, and water and hygiene solution into one system. And trying to establish an Infra-free[®] model of shelter for disaster area. The ultimate objective is to design a Temp Infra-free[®] model dealing with the sanitation and environment preservation concerns for disaster area.

Key Words: Infra-Free[®], Decentralization, Temporary Shelter, Integration Architecture, Closed-life-cycle

“The dream of yesterday is the hope of today and the reality of tomorrow.”
By Dr. Robert Goddard

1. Introduction

Nowadays, the International Space Station (ISS) is still on its construction. There is no any centralized infrastructure in space and there are nothing can astronauts' daily life needs but to recycle the reusable resource as more as possible. In order to provide enough life support condition for maximum 6 crew onboard the station, ISS equipped integrated environment control and life support system (ECLSS) to run the duty. ECLSS was first adopted in shuttle mission but due to its use of consumables and limited time it can stay in space, the advanced ECLSS is installed in the U.S. Destiny lab module and Russian Zvezda service module which includes the development of regenerable methods such as supplying water of recovering potable water from waste water or provides energy by transferring solar power from solar panels. The ultimate goal of this system is to reduce the reliance of space shuttle operation for resupplying fresh water and removing wastes from ISS and makes the whole space station becoming a self-reliant architecture eventually.

Moreover, since ISS is not a fully self-content architecture currently, and considering future manned space mission aims long journey to Mars or beyond that

would not be supported by any supplementary facilities launched from Earth, aerospace related organizations are doing effort on developing new life-support system to provide alternative solutions of cutting off high cost resupply launches such as ESA's MELISSA project, which goes further more to decompose organic wastes into usable resource through chemical process and produce food for crew diets than ECLSS serves mainly recycle the exhaled carbon dioxide and purify water.

As we learned more about ISS and other aerospace technologies which tried to develop a system or solution for supporting astronauts live in space; comparatively, the more we primarily rely on centralized infrastructure in metropolitan, the more fragile that our civilization is while unpredictable natural disaster (earthquake, typhoon, flood, etc.) or human caused lesions (human mistake, etc.) occurs. Especially when earthquake happens, it interrupts our life line directly and would probably collapse a city's aged infrastructure permanent; trying to find whether there is any possibility to introduce aerospace technology that is for establishing a self-reliant system into disaster supporting facility extends a new opportunity of developing a shelter which can be settled in without depending on external infrastructure.

It is paradoxical that a shelter not only has to serve as a mediate for “continuity” of sufferers' daily lives, but is defined to be “temporary” in disaster area. Since the nature of shelters is temporary and supporting period is

determined though, “temporary activities” for habitat inside the shelter do not exist and the living quality should not be eliminated; “shelter” not only serves sufferers to live comfort with its amenity but is claimed to have advanced performance for corresponding its environmental context properly. Currently treatment for shelters’ wastes solution, water supply and sewage solution are carelessness or insufficient which would cause secondary injury for sufferers such as influence disease.

Earthquake is an important key word for Japan or any other countries where have big earthquake concerns. We are trying to design a model for post-disaster management based on an example using Chi-Chi earthquake in Taiwan, which will be discussed in chapter 2 to work on an “Infra-Free[®]” architecture scenario for solving sanitation problem by integrating aerospace or advanced technology into one closed-life-cycle system. This concept could also be contributive not only for solving lacking sanitation condition in aftermath but could reduce wastes for each family in normal time.

Besides, aerospace technologies are researched and developed on Earth, aerospace technologies can be realized as “terrestrial technologies” strictly, therefore if we can transfer the know-how into developing a more efficient and self-reliable shelter model then we will have a system which is applicable both for space architecture and terrestrial one and to feedback to each other. We believe there are also possible for introducing terrestrial shelter model which integrated aerospace technologies into future planetary space missions such as destination Mars or Moon to establish manned frontiers maybe only plug in an air component.

2. Post-disaster context of Chi-Chi earthquake

2.1 Description

Happened on September 21st in 1999 which was the biggest earthquake in Taiwan since 1910’s earthquake, the magnitude of Chi-Chi earthquake was 7.7 and heavily damaged infrastructure networks were interrupted into two more weeks in most of regions in central Taiwan. It was a typical epicentral earthquake, also the focal depth of the earthquake was only 1.1 km which was a very rare seismic phenomenon so far especially the countries such as Japan, Taiwan and west America area in the Pacific Rim region, the most heaviest damaged area was not at the focal where the earthquake happened but streaked Taichung city where is more than 50 kilometers away.

Electricity, waterworks and transportation network were totally interrupted for two weeks since the earthquake happened, and thousands of sufferers left homes that might have collapsing concern and lived in prefab in park or gathered into gyms. Wastes removing was delayed and accumulated near the prefabs. High temperature caused influence spread out quickly, and portable toilets were not enough water for flushing; hygiene problem became the main concern which we are trying to focus on and to improve for future shelter designing.

2.2 Condition of shelters after Chi-Chi earthquake

Shelters depend on external energy source, water supply and external wastes removal facilities are required. Energy consumption of shelters increases energy loading in stricken area and a burden for local recovering activities.

Food and water supply depends on relieve from government or private rescue organization.

Emergency deployed shelters such as prefab are limited by the transportation situation during disaster period.

The technical skill is required for the assembly of emergency deployed shelters.

2.3 Sanitation concern in shelters¹⁾

Wastes were well collected but accumulated around the shelter openly which was to be the main concern for preventing from influence and disease.

Sewages which produced by sufferers everyday from shelter drained into gully directly could be found in many cases of severe earthquakes’ aftermath conditions.

Due to the lack of proper air ventilation equipment, the environmental condition inside the shelters was stuffy, humid and hot especially in summer.

Portable toilet is useful as modern emergency hygiene deployment though, without accompanying water supply, portable toilet is just a container of urine and feces and probably causes environment concern as a reverse effect. Also, the design of portable toilet is inconvenient for elders.

Because of the environment was dirty, Enterovirus and Rotavirus spread out quickly among the shelters.

2.4 Conclusion I

In aftermath conditions of many heavy earthquakes such as Chi-Chi earthquake we found that government or organizations tried to gather sufferers into gyms and mass capacity shelters, for now, many countries like Taiwan are widely using prefab as follow up sufferers’ habitat though, even in prefabs, poor sanitation condition that would probably speed up the secondary injury of an earthquake. For now, lots of equipments and facilities are introduced for solving sanitation problems but they are decentralized and not to be well organized into one system, which would be definitely reduced their mobility and efficiency; further more, matchless of each components conducts inconsistency not only for prefab residents but leads to chinks of disease prevention. According to government report, in the case of Chi-Chi earthquake there were more than 190 ton wastes per day produced by shelters, removing the wastes costs taxpayers for about 70,000 Yen a month and most of them were recyclable and benefit to those who were living in shelters for reducing the reliance of external expenditure burden. Seeking for compact and self-organized sanitation module is an adequate solution for shelters.

3. Infra-Free® technology

3.1 Post-disaster environment

After the earthquake there were lots of recovery activities need to be excused, the most urgent and fundamental objective is to repair and / or to reinstall the broken centralized infrastructure which was no longer “centralized” instead there was “decentralized” due to its aged materials and linkages.

Fig. 1. Time line for recovery of centralized infrastructure.
(Based on various sources)²⁾⁻³⁾.

Figure 1 shows that life supporting sources like electricity, gas, sewages and waterworks need a time frame of 2 to 4 weeks to get repaired. In this paper, we will intensively focus on water recovery technology which takes the longest time to be reinstalled by the case of damaged centralized infrastructure after the heavy earthquake.

3.2 Infra-Free® technology

The centralized infrastructure we rely on every day likes an umbilical cord which connects us and this modern civilization. Since we primarily rely on infrastructure as the basis of this world: Energy provides us electricity for lighting and automation facilities driven; waterworks and sewage deal with our needs for having potable water and wastes solution; transportation network fasten the distance between cities, etc., while unpredictable disaster occurs collapsing infrastructure would probably causes civilization crisis.

Infra-Free® (Infrastructure free) indicates an innovative approach for reconsidering improvement and opportunity for not having to rely on existing infrastructure which shapes our daily lives. The research of Infra-Free® (IF®) architecture unit involves adopting transferring aerospace technology and other contemporary solution into architectures from current situation to create autonomous environmental-friendly living units. The basis objectives of IF life are: 100% recycle of energy, waste, water and food; decrease amount of waste and improving reuse / recycle in community; increased resistance against nature by depending less on existing infra; Low-cost, low energy systems receiving less influence of topographic conditions.

3.3 The Infra-Free® Shelter (IFS) concept

As we define the needs and conditions after infrastructure damaged by any heavy earthquake, developing an Infra-Free® Shelter (IFS) module becomes an urgent issue particularly in metropolitan civilization which adopts infra-free® technology for developing emergency deployable evacuation facility.

The basis of IFS concept involves in monitoring technology, mobile mechanics technology and particularly advanced life-support technology. The whole concept is formed by following approaches:

- Shelter designing: the shelter is claimed to support sufferers' daily lives and should not be ignored especially creating the amenity and suitable living environment. Though we are trying to design a shelter which could feasible and used for universal design, the difference between cultures should be take account of.

- Mobile technology: such as light-weight and compact materials development; this implements the mobility and rapid deployment abilities which allows users and transporter free for heavy shelter components and local-constructing shelters.

- Closed life-support technology: capable to convert recyclable organic wastes into reusable resources for reducing the reliance on external temporary infrastructure; such as food producing system, water recovering technology, and organic wastes decomposing facility or CO2 heat pump heater; which provides wastes and sewage solutions, water supplement for shelters.

We try to propose a concept which combines shelter designing, mobile technology and closed life-support technology in this paper, especially the water recovery technique of closed life-support system and compact designing for shelters of post disaster management issues. The rest of IFS concept would be led to other emerging technologies as mentioned below:

- Energy co-generating technology: intended to provide necessary energy consumption for advanced life support system; such as fuel-cell, solar energy collector, wind power generator, or vibration electricity generator which transfers physical environmental condition input into clean energy for using.

- Energy storage device: to store electricity and serves as a relaxation oscillator of energy consumption. The energy storage device can be a back up supporting system not only for the shelter's self-reliant system usage but for unexpected need of sufferers.

These technologies are indispensable though, due to hygiene concern becomes the main issue in the aftermath of any heavy earthquake that disables the sewage and waterworks in a city and people who live in the shelter need clean water for drinking, keeping personal hygiene and most important thing is for solid and liquid waste solution. As a result, we will focus on water technology treatment and reuse.

Fig.2. IFS concept bases on various fields of technologies.

Fig.3. Infra-free® technology level schematics⁴⁾.

3.4 Overall concept for developing scenarios

In order to clarify the implement of IFS concept, we are here to quantify the need of water consumption for a family in Taiwan per day and it is on International Space Station for concluding appropriate water income and recovery quantity of Infra-Free® shelter for a family use for one month until the centralized waterworks reinstalled.

In architectural environment engineering we divided consumed water from a family daily lives into three types which are used for grasping waste water quantity of sewage solutions' definition:

- White water: potable water; ground water.
- Grey water: cleaning waste water from sink, basin, rain flows.
- Black water: waste water with composition of feces and urine from toilet.

The type of waste water involves the processing procedure of waste water recovery sequence that we propose to simulate for IFS developing steps primarily. The secondary step is to quantify the water consumption per person in a family in Taiwan, reference to the water necessity of Hansin earthquake in 1995 per shelter and compared with it is on board ISS in order to conclude the adequate water recovery quantity for a shelter.

Fig.4. Water consumption comparison⁵⁾⁻⁷⁾.

3.5 Conclusion II

Therefore, the criteria for IFS are mentioned as follow:

- The drinking water should be bought and resupplied from out side by military or government units.
- The filtration efficiency should be up to 90% recovered water is only for hygiene water usage (It may no necessary of recovering waste water into potable water such as it does on board the ISS due to its characteristics which needs only shuttle mission to resupply potable water).
- Water recovery system⁸⁾ mainly supports bathing and toilet water consumption for shelter which are the most important causality of sanitation concern after any disaster.

Fig.5. IFS water consumption scenario.

4 Infra-Free® Shelter (IFS) system scenarios

4.1 Main criteria

As we mentioned before to adopt aerospace technologies into shelter design though, the bottom line of water recovery quantity for a family (four persons) to live for about one month unlike ISS's operation is for 4 crews to live for 6 months; the most difference is that ISS needs high cost resupply operations to continue its task on orbit which is more extremely then that on Earth for at least one month until waterworks reinstalled. Therefore we conclude the water recovery quantity per person for drinking is 2L which is the basic needs for an adult's a day thus there's only 60L for a month; and mainly focus on bathing and urine and/or feces solution of shelter that we propose water recovery system for hygiene water usage since the acquirement of potable water is convenient from outside.

4.2 Scenario implement

To determine the quantity of recovered waste water for hygiene needs by analyzing the water consumption requirement in bathroom, kitchen and toilet which are the main places provides families water access normal times compared with critical needs in aftermath condition.

Referring to the water consumption in chapter 3, the recovered waste water capacity for Infra-Free® Shelter divided into 2 groups and solid waste solution.

- Potable water: basically a cartridge tank which can be installed and removable from outside the water recovery system. The capacity of potable water cartridge is about 60 liters which we concluded the basis quantity for an adult per day is 2 liters and 240 liters for a month. This includes food preparation water needs for a month is 180 liters all contented in a PW&FPW (Potable Water and Food Preparation Water) tank. The total capacity of the tank will be about 420 Kg and be plunged in the first week after the earthquake happened for “*Ensuring the minimum life support quality*” which is to provide enough potable water for drinking and for food preparing would be the most important issue above all.

- Hygiene water: the recovered waste water is mainly for hygiene use which we mentioned in chapter 3 considering the potable water can be carried and plunged into the system from outside. Due to the different cultural background in many countries, drinking the recovered potable water from urine and hand washing water would probably rejected at the first stage of developing Infra-Free® Shelter (IFS) model though, for survival it might be necessary after all and also stimulates the water recovery system used for IFS more matured to be accepted.

The Hygiene Water Tank (HWT) is plunged in the system for supplying hygiene water access in first week, and divided into 2 main parts: Bathing water and Flush water which would be recovered in rest 3 weeks to provide adopting family shower and toilet cleaning water needs. The recovered hygiene water is restored into ReHWT (Recovered Hygiene Water Tank) and would be refilled once a week by recovered waste water from adopting family's daily water consumption and provides family for hygiene water consumption in next week. It will be the self-consistency activity for the closed water recovery system at all.

The ReHWT's total capacity will be 339 liters (339 Kg) and included 3 parts: Recovered Bathing Water, Recovered Flush Water and other Hygiene Water. Each part filled by recovered waste water separately from it consumed repeatedly. Assuming the apogee water recovery system's efficiency reaches more than 98%, the recovered bathing water would be 280 liters; recovered flush water would be 28 liters; water from urine and other sources would be recovered in 31 liters.

- Solid waste solution: solid waste includes organic waste came from kitchen or feces from commode will be processed by organic waste decomposer and the residue collected into RSWT (Removable Solid Waste Tank) which capacity is about 15 liters (15 Kg) for adopting family use in 1 month and sludge.

Fig. 6 shows the water consumption quantity and weight shifting of all system.

Fig.6. Water consumption and tank capacity / weight shifting overall system.

4.3 Possible technologies or key words

Either potable water or hygiene water consumption in entire system should be eliminated as more as possible, we propose some technologies or key words assistants in the daily lives of adopting family for saving water and only fitted by balanced recovered waste water.

- Water tank material: made of CFRP (Carbon Fiber Reinforced Plastic) which is a common material used widely in aerospace field due to its light-weight, long duration and high tenacity characteristics. The density of CFRP is 1.6 g/cm^3 and as the scenario shows in the first week the plunged in water tank weights about 2 ton in system.

- Water saving for **Bathroom**: the basic proposal of the entire system is to ensure potable water and personal hygiene during the one month's supporting activity, therefore bathroom water consumption neither to be eliminated as the extreme condition as ISS nor centers all system's proportion of recovered water, thus:

>SMA valve: would be a good solution for returning continually flew away cold water and reuse until hot water comes out.

>Infrared sensor faucet: saving water just for users when hand or body nears the sensor and provides proper quantity of hot water (+ only 3V electricity needed by batteries).

>Non foam-up shampoo: adopted the same concept of those cleaners on ISS for astronauts washing hair and shower. That would be no necessary for flushing bubbles and just need very few quantity of water to clean hair and body.

- Water saving for **Cleaning** and **Laundry**: for a month washing clothes may not be the have-to-do job for sufferers, however considering the labor of putting things in order after the earthquake, we propose that the plunged in supporting system provides sufferers agreeable life:

>SMA fiber based non-woven shirts: as the same concept as the Smart Shirt⁹⁾ performs, its sleeves rolls up when temperature of air or body rises, and excellent breathing performance would be useful for preventing sweats and lengthens the wearable time. When it is dirty, no needs for laundry just throw it away into storage space.

>Hypersonic dry washing chamber: it is a concept yet but for cleaning the dirty shirts just by hypersonic vibration sound waves. It will be an excellent ideal dry washing technique which no needs water and other cleaners anymore; however, among of energy would be needed.

>Decomposable clothing: like throwaway tissues the shirts provides one-time use for sufferers, after wearing these shirts just collect them into the accumulate space and will be handled by biomass burning method.

>Reusable Self-decontamination sponge: a conceptual sponge which applying nanometer technology a special solution on its surface to clean dust and oil easily, due to the nanometer level holes on the surface the sponge would be cleaned easily with bio-technology it will decontaminate itself.

- Water saving for **Toilet**: toilet is the most important water access point in a house which for commode and urinal flushes. There are many methods for water saving on this issue though; the fundamental key point is the type of equipment such as urinal and commode. For reconsidering this issue also implies hints of developing new equipments.

>Water less urinal: water for urinal flush is not so necessary as the urinal made by grime hard attaching material such as nanometer technology ceramic urinal are very popular in many families in Japan or other countries.

>Water + Water less commode: there are two possible ways for commode: one is with a plenty of water pressure the feces could be flushed out and water and solid waste separated into recoverable flush water and organic solid waste tank to be removed; the other is to separate urine and feces in 2 different holes, and feces hole connects the organic solid waste tank and urine to be collected and recovered for flush water.

>Edible toothpaste: no water for washing toothpaste needed and could be eaten with potable water.

>Alcohol-Based cleaner: alcohol-based cleaner provides users convenient hand cleaning and other hygiene usage for not consuming water.

- Water saving for **Kitchen**: in this scenario we assuming kitchen is the mainly place to access potable water and food preparation water needs.

>Water flow-control valve: provides adequate quantity of potable water avoiding waste too much drinking water. It also allows users check the rest water quantity easily.

>Mixed-nutrient desiccate meal package: traditional meal needs among of water and have to use gas for cooking which is not a proper way to save limited potable water for one month's supporting activity. Thus we propose desiccate meal packages similar to astronauts' daily diet on space shuttle or ISS. Besides, for transportation interruption buying foods or waiting for community's supporting would be danger and difficult. The mixed-nutrient desiccate meal for a man needs 500 cc water for preparing and might put in a special pressure chamber (less than 1atmospheric pressure) for heating water and ready for meal.

>Edible tableware / Throwaway tableware: edible tableware made from dried bread mixture with rice, it can be used as bowl and cup and be eaten after the meal with no harmful effect at all. It is ecologically friendly and convenient for users to save dish washing water. Throwaway tableware also could be a solution for saving water and those might be able to be decomposed by biomass after the supporting activity.

The overall water recovery system schematic is shown in Fig. 7 in next page. It implements the processing sequence, capacity of each accumulating unit and possible technology key words **Into input / Output** section, **Use / Used** section, **Generate** (waste water recovery) section and **Accumulate** (recovered hygiene water tank) section.

Fig.7. Infra-Free® Shelter (IFS) supporting system overall concept.

Fig.8. Water recovery system insertion.

Fig.9. Water recovery system space in IFS scenario.

5. Further research

To implement water recovery sequences and capacities apparently is the first step of sketching the entire Infra-Free® Shelter (IFS) designing. There are still many accompany life support sub-systems for supporting sufferers' live inside the shelter at least for a month such as energy generation system and other technologies would be required like self-deployable mechanic, etc. which are not discussed in this paper though, there are still lots of space for it and will be the next step for completing the whole project. As we found there were many who did not want to leave the temporary shelter and became a social problem lasted a long time and that also be a good stimulus for developing IFS and hints that the shelter is not only a "*Temporary protector*" in aftermath area but an "*Self-evolutional organic living context*" only as it is necessary to be extended the deployment period.

6. Summary

Water recovery system for Infra-Free® shelter provides emergency either potable water access or solving hygiene problem from a fundamental approach of inserting water supporting components and for deducing the reliance to just repairing infrastructure by adopting waste water recovery method.

The flowing researches will mainly looking for adequate integrating technologies for supporting the system and other possibilities of developing IFS to reach a complete self-reliance shelter.

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