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Networked Energy "Mainboard" Platforms

A New Concept for Closed Loop Resource Utilization in Open Building Systems

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ABSTRACT:
Combining synergy, self-sustainment, modular living and advanced electronic systems in a customizable and adaptive package seem to be a logical step towards the goal of lessening the human impact on the environment. The exaggerated use of water, energy and other resources continue until this day, despite the fact that the world is running out of resources. Alternative energy and water resources are widely researched in hope of providing self-sufficiency in scales of single houses up to communities, but are still limited to demographical, economical, technical and social factors which vary globally. In this paper we present the conceptual idea of a pre-fabricated, self-sustaining, interchangeable and standardized platform, which is situated beneath a modular home, a so-called mainboard- inspired one, by the principle of computing, which houses and electronically controls all water installments and energy components needed for a household. The system is conceptuated in a way that allows multiple mainboard platforms to interact and interconnect with each other in order to form a synergetic relationship between a mainboard cluster and it's individual components. Furthermore, this paper discusses the subject of Intelligent Energy Environment/Networks, where the Mainboard cluster is seen as an "artificial organism" that is able to undergo a constant evolutionary transformation in order to learn, adapt and redesign itself to be able to enhance the synergetic relationship in the mainboard cluster. Finally we study the scenario of rapid Mainboard deployment, a fast and efficient way to found scalable communities.

Conference Topic: Integration Issues (Economy, Society and Environment).
Keywords: Mainboard Design: Embedded Systems, Energy Communities, Modularization, Mass Customization.

1. INTRODUCTION

1.1 Background and Purpose

Modular housing has been proven to be a very cost efficient way of construction, but it has yet to convince of a overall efficiency. A generic design and a focus only on cost efficiency and individual housing projects have strained modular housing from becoming a truly successful way of living in many parts of the world. A modular home needs to be more than just four walls, it needs to be an intelligent and, particularly, energy efficient home with a life cycle equal to that of a conventional home. In addition, it architecturally needs to be at least equal to a standard home. The challenge of constructing such a modular home lies not only in the technological device incorporation, but also in creating an energy efficient, intelligent, self-sustaining and highly modular and scalable solution. Thus we present the concept of a modular and highly compact and customizable energy platform (Mainboard), on which various energy relevant subsystems, technologies and appliances of houses and condominiums can be installed and interconnected to ensure a continuous energy equation. Those Energy platforms are designed as systems, which can easily be integrated into modular Open Building Systems as a compact unit. Further, energy platforms distributed over several houses or condominiums can be interconnected in order to form cooperating clusters and energy communities.

1.2 Review of Previous Concepts

Concepts for the Modularization and Prefabrication of various construction types as steel, wood and concrete for various purposes as Housing, Condominiums and Office have evolved in Europe, Japan and the US (Bock, et al. 2009). Modularization and industrialized production of buildings have been developed further especially in Japan and have many analogies to automotive production today. They show that a continuous production line processing becomes possible by the introduction of a three-dimensional steel frame being used as "chassis". A further important contribution to large-scale industrialized and customized manufacturing of buildings is the legendary Toyota Production System and it’s cell/unit prefabrication method (Linner, et al. 2010). The changeability of modular buildings through modular infill has been introduced by J. Habraken’s Open Building Approach (Habraken, 2000) and has been improved by S. Kendall (Kendall et al., 2000). Approaches for the organization and structure of building sub-systems and in-house infrastructure are provided by Fritz Haller’s Armilla Installation System (Hovestadt, 1998) and John Habraken’s Matura Infill System (Habraken, 1995). Both systems organize and modularize classical building service sub-systems as water-sewage system, ventilation, air conditioning, heating and electrical cables. Fritz Haller’s system was designed to systemize and modularize the building’s installation systems, support industrialized prefabrication and give the overall building component system the potential of rearrangement and/or extension. Various concepts for highly energy-efficient buildings have been developed during the last decade. Passive Houses for example are low energy buildings requiring less energy for space heating or cooling (Schnieders, 2006). The concept of active houses or surplus energy houses (EU, 2009) even goes one step further by introducing houses, which can generate more energy than they consume. Further, Intelligent buildings, fully networked homes and a multitude of smart appliances gradually enhance the performance of buildings (Linner, et al. 2010). Energy management systems guarantee an intelligent real-time control of energy- and consumption-related appliances of a house. Various systems generating energy can be interconnected (Torbensen, 2008) and it is possible to record, control and analyze room temperature, air circulation and excess heat. Increasingly all energy relevant components of a house (windows, doors, heating, photovoltaic, aeration) can be equipped with Microsystems Technology, connected to energy management systems and controlled proactively as shown for example by Toyota's Prototype House PAPI (Shimizu, 2005), Panasonic's Eco & UD Concept Home and Siemens T-Com House (Siemens, 2006). The idea of Smart Grid Technology even extends the smart building approach towards energy control on community or city levels (Vittal, 2009). In this paper the outlined concepts of open building modularity, flexible installation systems and intelligent building technology are brought together to a new approach. Various modularized energy technologies and smart appliances can be installed on an integrating platform offering both physical and digital integration. The platform allows a prefabrication of the building's energy platform and serves as a compact "chassis", which can be customized to different circumstances and needs. The Platform with all energy technologies, appliances and systems installed is an entity which becomes an exchangeable sub-system of a modular building. In this paper we focus on a framework for the energy platform. Specifications for modular buildings, into which this platform can be integrated, will be developed in further papers.

1.3 Study Target and Research Methodology

Our study target is the conceptual idea of a pre-fabricated self-sustaining, interchangeable and standardized platform situated beneath a modular home, a so-called Mainboard- inspired by the principle of computing, which houses and electronically controls all water installments and energy components needed for a household. The system is conceptuated in a way that allows for multiple Mainboard platforms to interact and interconnect with each other in order to form a synergetic relationship between a mainboard cluster and its individual components. Furthermore the paper discusses the subject of Contionous Energy Transformation where the mainboard cluster is seen as an "artificial organism" that is able to undergo a constant evolutionary transformation in order to learn, adapt and redesign itself, so that it enhances the synergetic relationship in a network of multiple Mainboards. Therefore the paper is structured as following: in Sec. 2 we first define requirements for energy platforms. We continue in Sec. 3 with deriving the physical and digital system architecture from the requirements identified. Application scope and Deployment strategies are the topic of Sec.4. The paper is concluded in Sec. 5. The paper aims at showing the interdependencies of requirements, system architecture, Mainboard communities and deployment strategies. Technical aspects will be outlined in detail in further research papers.

2. DEFINITION OF REQIREMENTS FOR ENERGY PLATFORMS

Designing assistive pervasive systems is a multi-dimensional, interdisciplinary challenge. These challenges, which are illustrated with examples from current research efforts, have to be considered throughout the complete development process. Further, a multidisciplinary team for research and development is required. During the development of the Mainboard platform concept, a main issue was the continuous balancing of the requirements of the participating research fields. In this section definitions of requirements for Mainboard platforms are presented,which have derived from those research and coordination efforts.

2.1 Standardization and Platform Strategy (Mainboard)

Integrated resource management is based on simple engineering solutions, which are combined to create more complex systems to reduce losses and improve resource productivity, but with higher costs and difficult maintenance procedures. If the Mainboard could provide a standardized platform like a computer motherboard (See Fig 1), plug-in technologies could be rather simple but initiate innovation boost and cost reduction through the competition among technology suppliers willing to deliver standardized modules to any region in the world.

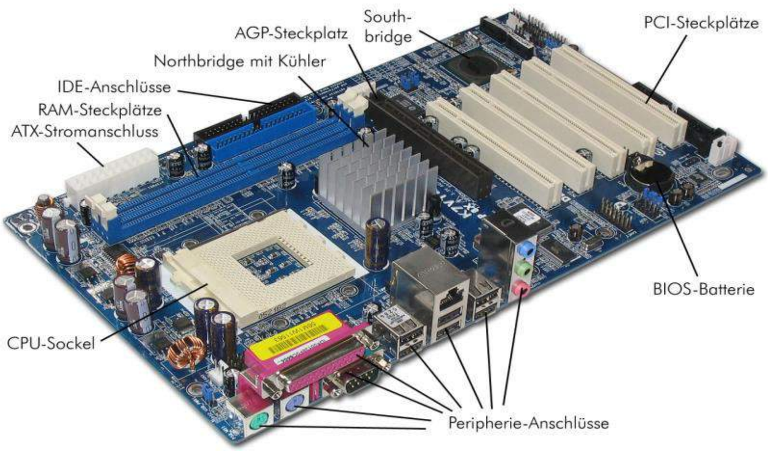


Fig. 1: Example of a computer Mainboard which allows customization through plug-in and attachable dedicated modules. The presented Mainboard Platform provides a standardized platform for the integration of various modularized energy technologies and smart appliances to a compact and prefabricated entity.

2.2 Mass Customization and Prefabrication

User choices are numerous and depend on a multitude of unpredictable factors. For example, a user with high-economic income in a developing country might prefer a completely decentralized household, while a user with low-income in a developed country might prefer to add just a single unit, or vice versa. Thus, user preferences lead not only to the choice of technologies, but also to the resource consumption patterns that might vary due to family structure, culture, choices and other factors. Thus the difficulty in proposing a decentralized household is not a problem of technology, but the problem of user choice and environment. Today industrial production of individual products, which is also referred to as "Mass Customization" (Piller, 2008) is increasingly enabled in a multitude of industries through new production technologies, self-organizing production processes and material flows able to cope with dynamically changing economic environments: just-in-time, just-in-sequence, and just-on-demand.

2.3 Embedded Microsystems Technology

Microsystems Technology gradually permeates all possible application fields within buildings. In the future this application fields will gradually be interconnected to generate synergies until the whole house becomes a distributed and networking system of embedded technologies and cooperating sub-systems able to assist multiple use-cases. If all systems and subsystems installed on the Mainboard are equipped with compatible micro-systems, the desired functionality could be determined by allowing the platform to operate by an artificial control system providing mandatory or voluntary resource conservation and/or reuse patterns depending on demography and use of sources.

2.4 Compatibility of Plug-In Systems

Different middleware systems, such as GAIA (Roman et al., 2002) and MundoCore (Aitenbichler et al., 2007) have been proposed and used in the relatively young research field of pervasive and ubiquitous computing. The challenges of distributed multimodal information processing connecting heterogeneous input and output technologies have very different demands towards middleware systems. Unfortunately, reuse and finally development in our domain is usually limited to the initial developers of a respective middleware and no community yet evolved to pursue the ambitious goal of a unified middleware. Existing systems, therefore, have not been designed to have a long life cycle and to allow future inclusion of demands and upcoming technologies. We, therefore, consider the middleware as an extremely important issue towards deployable and working systems. Later on it is described how we hope to have successfully have tackled this issue.

2.5 "ImmoBots" and Real-time energy equalization

Environments enriched with "sensor" and "actor" systems given certain autonomy and able to control their complex internal functions are considered as "ImmoBots": Immobile Robots (Roush, 2003). In general, those systems can cover networked building energy systems as well as power grids or reconfigurable traffic systems (McCandless, 2006). Further systems as photocopiers able to coordinate a multitude of internal subsystems with a model based programming approaches or whole cities equipped with smart subsystems can be called "Immobile Robots". If multiple Mainboards are applied in a community, the communication between these modules could provide a switch from known one-directional resource flow into a multidirectional decentralized supply network controlled by "Immobile Robots". Here, the capability of Mainboard networks to recognize attached system components is necessary to calculate real-time energy equalization due to the needs of community.

3. SYSTEM ARCITECTURE OF NETWORKS AND MAINBOARDS

In this section we present basic principles and guidelines for the design of the system architecture of Networks of Mainboard platforms and single Mainboard Platforms. The system architecture was developed in a top down approach going from the system architecture of the network down to the system architecture of Mainboards.

3.1 System Architecture of the Network

The Mainboard approach enables smart customization through dynamical technology integration and easy and fast configuration by a network of Embedded Systems. This principle could be transferred from a single Mainboard to a cluster of Mainboards. As these clusters set up a flexible, intelligent, cross-linked living environment, they could react as one adaptable organism to changing needs and occurring situations, the distributed system could re-configure automatically based on action patterns and probabilistic assumptions. If necessary, new appliances, plug-ins or subsystems could be installed on single Mainboards and thus contribute to the whole network.

3.1.1 Multilevel Network Integration

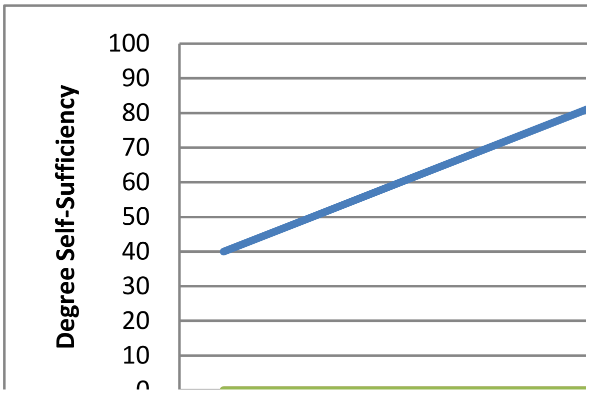
When constructing a network cluster, two networks are to keep in mind. The technical and the social network. It is essential that the position of the modular homes i.e. Mainboards is optimal for both flawless energy/data transfer and social contact. It is well known that energy- and data has its maximum transfer rate on linear paths and that the distance travelled has an impact on the transfer rate in proportion with energy loss. Positioning the Mainboard modules in a close linear pattern would not only maximize the network transfer rate but also advocate the communal social activities in turning away from traditional individual housing.

a) Social Network: Terraced housing has long been proven a success in countries like the Netherlands, British Isles and Scandinavia. Due to the cost-efficiency ratio and high level of pre-fabrication and not to mention the small plot size needed to erect a house they continue being built. This concept suits the general concept of a Mainboard housing cluster in its constructive linearity and height i.e. multiple floors. The social aspects of a terraced house are already well known and risks of disapproval would be at a minimum depending on the architectural design. (See Fig. 2)

b) Technical Network: The purpose of a technical network is the sharing of resources. The mainboard is conceived to sharing not only software but also hardware. E.g., each household has different energy needs during a day. The inhabitants of household A might be at work while the inhabitants of household B are at home with 60% of all electrical devices turned on. The AET (Active Environmental Transformation) system (detailed in Sec. 4) of the connected mainboards recognizes the energy deficit of household B and the surplus of household A and automatically channels the energy produced by mainboard B to mainboard A. With added households/modular units, this organized “work sharing" becomes more efficient. The energy production/usage would eventually even out or have an energy surplus. Another advantage of such networking is that in case of device failures and maintenance the workload of both software and hardware can be distributed throughout the entire system by usage of a central cluster network switch. This system is based upon the concept of a RAID (Redundant Array of Independent Disks) system and its work sharing environment, which presents the system with a faster and more secure transfer rate.

3.1.2 Self-sufficiency vs. Networks

The mainboard is not only an individual module with a lot of capabilities, but also a module with the capability of “intelligent integration” to other modular units and mainboards. This integration allows “networking” between several modules and the possibility of forming a large network of units capable of self-sustainment, where the degree of self-sufficiency is proportional to the number of mainboard modules in a cluster (See Fig.2). The concept of self-sufficient networking is continued throughout the mainboard, reaching from the micro to the macro scale. (See Fig. 3)



$$\sum_{a=1}^{n} M_a * (B) * (C)$$

n: Number of Mainboard components
a: Mainboard component
M: Mainboard
B: Number of Mainboards in community
C: Number of communities

Fig.2: Degree of self-sufficiency vs. Number of Mainboards / **Fig.3:** Energy calculation

3.1.3 Decentralized and multidirectional energy flow

The general idea of interconnected Mainboard platforms is to reverse the main direction of energy flow. Conventional infrastructure is based on centralized organization and one-directional supply with energy, water and sometimes steam. The end users are more or less dependent on the supply. The amount of energy produced and provided is in general more based on average calculation than on real–time-processing. With Networked Mainboard platforms every single unit represents a potential “part-time power plant“ having the ability to independent resource generation. In contrary to its conventional counterpart it is non-exclusively providing connection-standards for existing infrastructure and small local bio-power plants, which can be added as modular components. The energy generated by a single Mainboard and other added systems is distributed through intelligent and self-learning cluster controllers by best performance principles always aware of the amount and availability of resources in all systems and subsystems. Interconnected Mainboard platforms outline the path from centralized and one- directional infrastructure to decentralized and multi-directional energy equation.

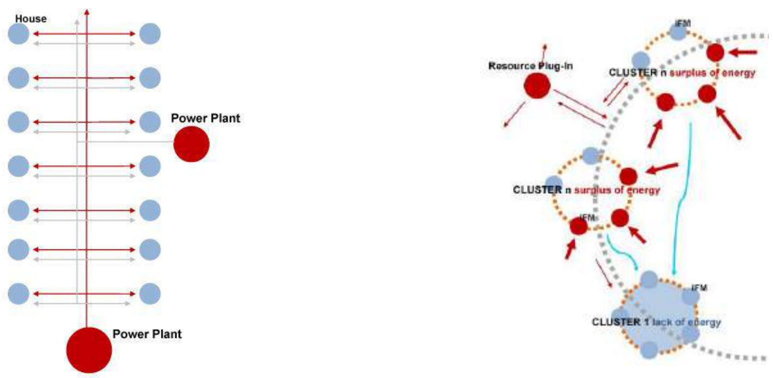


Fig.4: Networks of Multiple Mainboards **-** Conventional infrastructure: centralized and one- directional (left side); Mainboard Network: decentralized and multi directional (right side)

3.2 System Architecture of the Mainboard

To be fully functional in the in Sec. 2 defined way, the mainboard stands underneath the modular housing in a rectangular framing system with the longer sides facing the other mainboards in the cluster. This allows greater connection-surfaces and less data transfer distance between all mainboard units. A modular based assembly and bodywork creates a structural composition that renders the Mainboard safe for future component changes or expansions. Furthermore, the Mainboard can be completely exchanged in case of total malfunction or system change without the tearing down of the living module. The Mainboard itself is divided into five main parts (see Fig.5). The positioning of the four outer parts facilitates in case of any future system changes and heightens the data/energy transfer within the board due to the parallel arrangement and the homogenous space availability. Subcomponents are placed due to degree of interchangeability and usage. E.g., the part being in charge of all liquids is easily accessed from the outside, since grey water and filters need regular maintenance or exchange. All hardware on the board is exchangeable in order to keep the board flexible and compatible with future needs.

3.2.1 Hardware

The Mainboard system is a conglomerate of autonomous waste, water and other subsystems all controlled by a centralized ECU (Electronic Control Unit) based on the automotive industry, the most important part of the system and considered to be the brain of the mainboard. The ECU stores and controls all data on the board and is in charge of the dataflow between other mainboards and is accessible from inside the modular house in order to facilitate a possible software upgrade or maintenance. All other Hardware components inserted in the four outer parts are dependable on the user, technological, demographical, economical and social factor which vary around the globe. The concept is to have a modular basic package that can be expanded or exchanged depending on the previously dictated characteristics with a focus on an optimal synergetic relationship between the individual boards. The inserted components should complement any optional exterior energy source. Once assembled, the Mainboard would recognize the components installed and immediately connect to the surrounding Mainboard system thereby changing into a “work-sharing” environment.

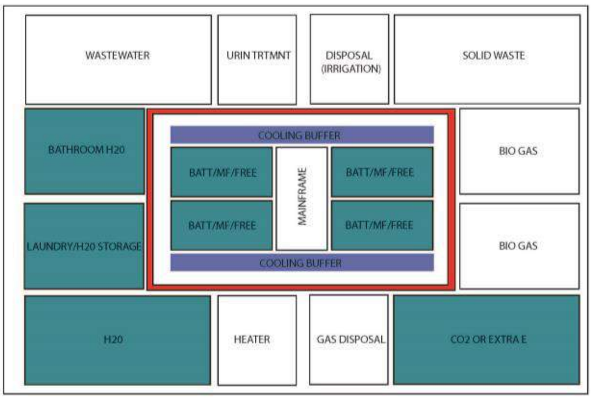
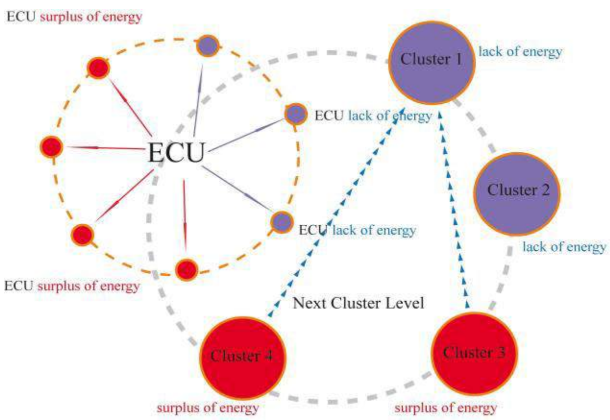


Fig.5 Modularity and Mainboard Hardware Concept The Mainboard itself is divided into five main parts and subcomponents are placed in order of degree of interchangeability and usage

3.2.2 Software

In a cluster of Mainboards it is likely that a single Mainboard temporarily generates a surplus of energy or resources that cannot be effectively used meanwhile other Mainboards at the same time need more energy than their treatment plug-ins or their batteries can generate. Due to habits, profiles and action patterns of Mainboard inhabitants, Mainboards are generally in different states concerning energy and resource consumption (see Fig.6). So for example it is possible that two Mainboards have a surplus of energy meanwhile another in the same cluster needs energy urgently. Before the energy is then taken from outside supply resources the cluster controller first checks the possibility of energy equation within the cluster. If this is – however- not possible the problem will be handed over to the next higher cluster level and the controller there tries to ensure the energy supply from within the system by driven by superordinate PDE Algorithm and best performance principle.



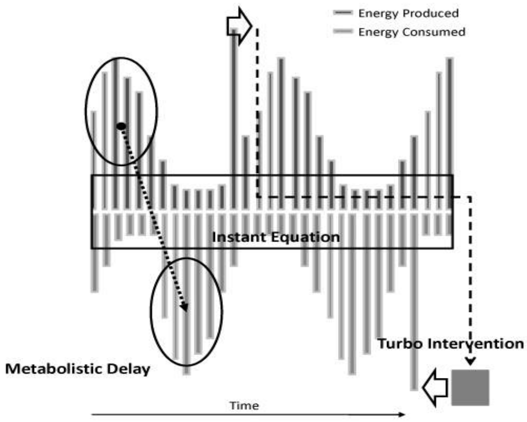


Fig.6: Network Organization and Energy Equalization Concept based on AET (Active Environmental Transformation) and RAID (Redundant Array of Independent Disks) / **Fig.7:** Scheme of Energy Equation and Energy Transformation in a Mainboard Community

Since the system is a networking system, all functions would be accessible from a terminal located inside each modular housing component. As administrator one could update all components whilst logged on to the individual mainboard or all mainboards in the network from each terminal logged on to the network. Each household member would be able to control the components applicable to the household needs and simultaneously have access to energy status, statistics, usage, etc. The goal of the network software is to have as much information as possible whilst as administrator is able to make routine checkups for the whole mainboard cluster.

3.2.3 Middleware

By treating Mainboards integrated with various sensing and actuation components as ImmoBots, we took the view of a robotic systems developer on distributed heterogeneous communicating pervasive computing systems. Following an interdisciplinary approach, we investigated the current state of the art of distributed sensing and actuation. The successful transfer and application of a robotics middleware Player (Collet, et al.2005) in the domain of pervasive computing has been already been shown (Kranz et al., 2007). The Player has been the de-facto standard and has been jointly developed for more than 10 years by the robotics community and reached a maturity far beyond other systems in pervasive computing. The successor middleware, ROS (Robot Operating System) (Quigley et al. 2009), is downward compatible w.r.t. existing drivers and includes many modern concepts of distributed architectures. This includes decentralized peer-to-peer network concepts, publish-subscribe information distribution or bi-directional services between components. The middleware not only allows inclusion of sensing and actuation systems, but also to visualize and simulate, both the information flow and the physical space, using e.g. OGRE (OpenSource 3D Graphics Engine) and ODE (Open Dynamics Engine) open source engines. This allows designing 3D objects in a CAD style manner.

3.3 Strategies for Continuous Energy Transformation

Based on the active control of all actuators and applications, the whole community built on the Mainboard concept could be seen as an "artificial organism" that transforms to keep the generated and consumed energy streams in a steady fluency. This means that house could transform its purpose over day by manipulating the actuators, which switches the Mainboard function over day and year due to source availability and individual needs. In order to counterbalance production and consumption in a Mainboard community, we propose three basic strategies, as shown in Fig.7.

- Instant Equation: As a preliminary process of energy equation in the Mainboard, the controller routes subsystems and applications to archive a high ratio directly interconnected energy counterbalance.
- Metabolistic Delay: Due to heights of consumption and production occurring in the Mainboard a constant 100% Instant Equation will not be possible. Therefore the controller manages energy conversion to be delayed over time.
- Turbo Intervention: Sometimes unexpected patterns or actions of modular home inhabitants are likely to cause sudden height of energy generated or consumed, which could boost the energy of the "Turbo Intervention System", that is an insurance against a sudden stand-still of the real time processing energy equation.

4. PERFORMANCE AND DEPLOYMENT STRATEGIES

4.1 Integration of Mainboards into Modular and Open Building Systems

Prefabrication: The mainboard is a completely pre-fabricated system. Each mainboard would be constructed to fit the region or city it would be sent to. E.g., in the northwestern part of Europe there is an abundance of wind. So each system would be provided with a kit that could channel the harvested wind energy. This would also work for photovoltaic elements in sunny regions and so on. This kind of construction of the mainboard allows future energy systems to be used and energy channeled, meaning the system is not bound to current technologies. The design of the mainboard also plays a role in transportation. The prefabricated elements can be shipped in parts and easily set up on site or the complete mainboard could be shipped as a whole.

Adaptability and Scalability: The modular architecture of the Mainboard Platform and the Middleware system allow the unrestricted scalability of the system from a single Mainboard unit up to huge and highly efficient Mainboard networks. Due to the system architecture outlined in section 3, and due to its customer related modularity, the Mainboard platform enables industrialized components production and supply networks offering customized solutions. Three levels on which the system could be customized to local habits, energy situations and individual needs: a) the mainboard itself; b) the components and subsystems added or installed on the Mainboard; c) Mainboard Network and Community Level.

Maintenance and Serviceability: The maintenance concept concurs to the one of modern race cars. Modern race cars are all pieced together upon a solid framework "cockpit" that holds the pilot and all onboard instruments. All pieces of the car that are changed frequently are easily accessed and the parts that are not changed very often are closer to the core i.e. pilot since they require more time to change. The mainboard is constructed the same way to occur quickly and efficiently. Since the mainboard is viewed upon as a permanent structure and not a temporarily one, it is essential that all parts are exchangeable into future formats, i.e. technologies. The mainboard is for future formats conceived in the way that it has different exchange layers like that of the racecar. It can be completely changed and replaced as a whole or partially changed. The procedure would be like that of changing the under carriage of modern electrical car.

4.2 Concepts for a rapid deployment of Mainboard-based Communities

Due to the nature of the pre-fabricated compact construction of the Mainboard, the possibility persists of using the Mainboard for purposes of rapid deployment. A rapid assembly concept and a light weight construction render the Mainboard a real alternative to traditional deployment methods. The scenario and demography would dictate the way of insertion. One scenario could be the founding of a research community in an arid region, where the absence of resources is a major factor. Because of the compactness of the Mainboard and the ability to be stacked, it could easily be deployed from a ship (see Fig.8). The researchers would within a reasonable amount of time have a well-functioning Mainboard community that, depending on the number of Mainboards, could be self-sufficient. Also the Mainboard cluster would be an environmentally conscious alternative to the research units implemented in recent areas and would have the advantage of future technology implementation with a long life cycle.

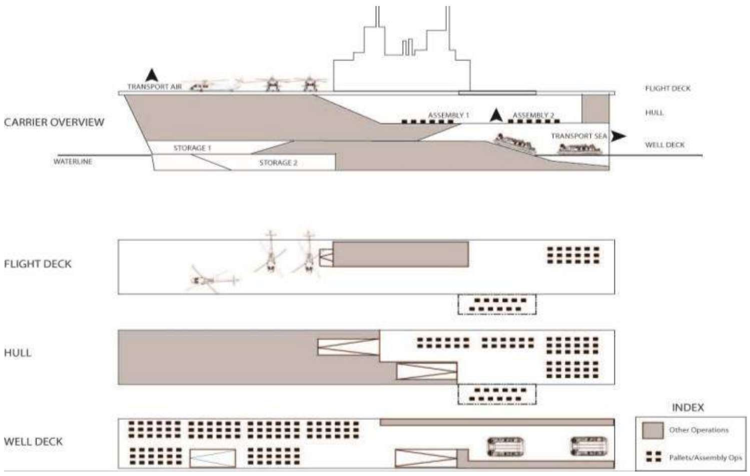


Fig.8: Rapid Mainboard Deployment through Prefabrication on a converted aircraft carrier ship

5. CONCLUSION

The mainboard system would be a logical alternative to traditional housing concerning efficiency, self-sustainment, design and flexibility. Small colonies could easily be erected and quickly be completely self-sufficient in energy and water (depending on precipitation of the region). Due to prefabrication, adjustability and a fairly low production cost, the mainboard system could also be an alternate option for lower income families. The key to the mainboard system is the number of mainboards in a network. The larger the network, the more self-sufficient the mainboard cluster is. In conclusion, since the mainboard system is prepared for future technologies thought its prefabricated technical design with all parts being exchangeable, the life cycle of the mainboard would but supersede that of traditional housing and in turn be self-sufficient. In further research papers the system architecture will be described in detail according to the concept outlined in this paper. Also the prototypic system validation conducted through a implementation on the open source Arduino platform will be presented in further research documentations.

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