ACTION-BASED 4+1 SYSTEM OF LIFE CYCLE HOUSING MANAGEMENT

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Abstract: The author proposes the action-based 4+1 system for management of a constructed complex or construct, which consists of four operational functions and one integral function. They are “self-descriptive”, “self-sensing”, “self-image over history”, “self-search”, and finally their integral function, “self-judge”. The management system attempts to establish the means of real time adjustment between design firms, builders, and component material producers, not least to mention the owners or occupants, in short for the means and benefit of all the stakeholders throughout the lifecycle of a construct.

Keywords: Ubiquitous 4+1 Management System, RFID, Sensing House, Active Database

1. INTRODUCTION

In manufacturing factory, most of production facilities for cells and stations are positioned at rather fixed locations and are often linked for their information processing by local area network or otherwise. In the sharpest contrast possible it may be, most of facilities at construction site are often temporary, mantled/dismantled tactically, and are changing their locations restlessly throughout the whole production period. It is not a trivial matter to link these temporary facilities to form an integral management system for processing, not least to mention communication network alone. In a factory, a pre-processed product becomes gradually processed in sequence as it passes through cells, stations, and lines. Its frame of coordinate to detect the current status, spatial and temporal position of parts and materials is fixed. On the other hand, in the case of construction, the frame of coordinate is changing as it proceeds, primarily because both the product and the production environment are themselves metamorphosed ceaselessly as its product is being built. What was built till now interferes with what to be done next. This very dynamic linkage between construction processing and its environment makes it hard to realize a highly secured, flexible and intelligent construction method, which is so much desired. It is not perhaps even possible to its full realization, unless it succeeds to decouple these inherent non-linear coupling within the production system. One possible solution to decouple them at least locally is to unify “parts and packets” via distribution of RFID over parts and environment in-situ, for the chip-implanted parts or environment behave as if they spontaneously send messages to their proper addresses to communicate at will, whenever their state are changed, and move around freely within the production system as if each of them provides its local coordinate of reference.

A similar problem persists over dwelling, only in a longer span over time and at a slower pace of change, throughout the life cycle of the constructed. There are three stages for the constructed, “To Create”, “To Live”, and “To Revitalize” throughout their life cycle. As the internet has brought about in the domain of universal information exchange, the RFID may provide us with unprecedented opportunities for universal control of the produced over their history. The author proposes in this article the action-based 4+1 system for management of the constructed, which consists of four operational functions and one integral function. They are “self-descriptive”, “self-sensing”, “self-image over history”, “self-search”, and finally their integral function, “self-judge”. The management system attempts to establish the means of real time adjustment between design firms, builders, and building material producers, not least to mention the owners, in short the means and benefit of the stakeholders for all throughout the lifecycle of the constructed.

2. DYNAMIC CONTROL BY INTEGRATED PARTS AND PACKETS

Control of construction process must deal with a bulk of scheduling elements that are produced by multiple heterogeneous players, contractors, sub-contractors, and parts makers. Their scheduling elements are necessarily intermingled and linked with each other. The whole schedule is managed and adjusted as one giant flow of processes. One small change in a tiny part of the whole schedule may possibly propagate its influence into the whole [1]. Every such complex system which is likely non-linearly linked often shows some chaotic behavior and leads to a catastrophe at worst. There are varieties of causes that force scheduling change. It is of critical issue when a signal of change is dispatched within a complex system. If timing gets lost, disastrous consequence may result with severe cost loss. It is also critical where a change occurs among multiple players, as well as what happens.

Construction is surely production activity, but is better characterized as project-type production. A project type production may be defined as "*a course of concerted action intended or considered possible to achieve some chosen production purpose for a given period of time under some given constraints on available resource (man-power, material, money) and construction environment*"[2]. It is therefore of critical importance to allocate production activities properly according to the well-planned process model and scheduling. It is equally indispensable to follow the exact flow of material parts both within and between activities to orchestrate the project properly. A large bulk of material parts come and go busily on site. The checkup of ordering and actual receipt of material alone causes hindrance or halt of the ongoing project more than often, which leads to severe economical loss. The utilization of an equal bulk of RFID's with a proper control mechanism (called Glue Logic to be later described) is one of the promising technologies (so identified among the currently available) that may provide the mechanism to achieve the required dynamic equilibrium for construction activity without hindrance or halt (Fig.1).

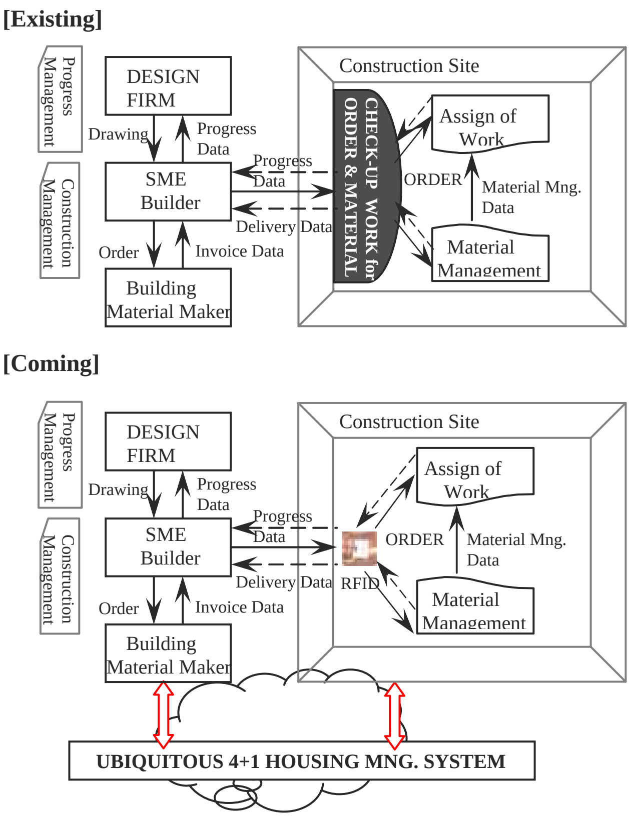

Fig.1 Production Control by Parts & Packets Unification

Upon completion of production, the hubble-bubble over the production theater ceases and halts, when the next phase of lengthy period for "LIVING" enters into stage. Every constituent of the constructed complex, houses or otherwise, begins its gradual entropic decay in the due course. Any constructed complex has deep hierarchical echelons both in temporal and structural orders- structural frames (50 years), partitions (25 years), finishing material (10 years), mounting units (10 years), fixing (5 years), material consumed (2.5 years), commodity (1 year), consumption article (1 month). Although the clock of decay seems to pass by much slower in average than that of construction, a cohort of decaying processes acts on the constructed complex here and there, from far and wide. The interdependence of assembled parts with interpenetrating functions over different echelons remains intact. It may cause, at worst, a sudden hindrance or halt on the proper functioning of a house similarly as a halt of construction activities when under construction. The big gap between them is though that decay process is largely intangible and beyond anybody's view in contrast with construction process essentially under everybody's watch.

The part and parcel of the life-cycle control of housing assets is therefore to "visualize" the compound decay processes and to engineer prevention against inevitable degradation over the constructed complex. Parts and packets unification will do restore the symmetric principle of engineering between creation and degradation so that a coherent control mechanism could be developed for the whole life-cycle of house, which is constituted of three stages, "to Create", "to Live", and "to Revitalize".

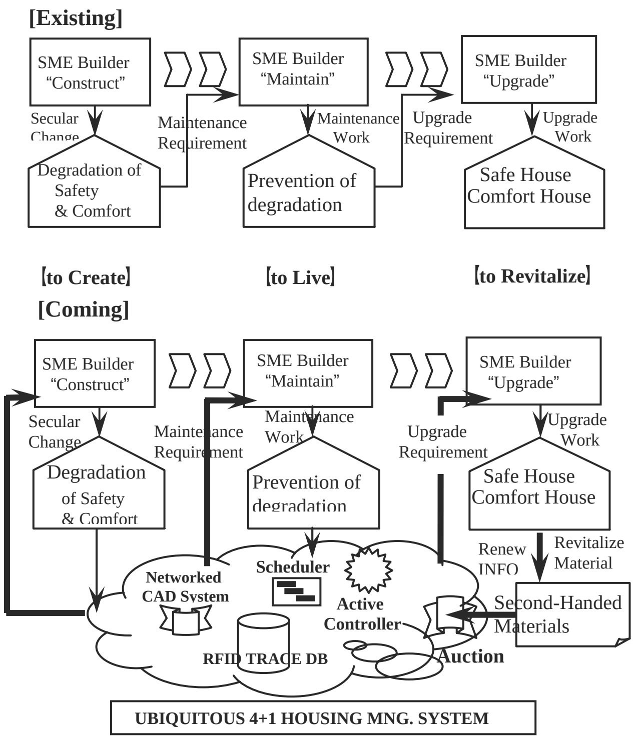

Fig.2 Life-Cycle Control by Parts & Packets Unification

Such coherent control mechanism is coined as ubiquitous 4+1 housing management system in this paper, and is depicted above at Fig.2.

3. UBIQUITOUS 4+1 HOUSING MANAGEMENT SYSTEM

Among three stages over the whole lifecycle, the second and the third stage, i.e. “to LIVE” and “to REVITALIZE” overwhelm the first of construction stage by years of relevance. One of the primary concerns on the later stage is how one can reorganize the design information which describes the current state of every part in the house from every element of skeleton to all the pieces of infill into details. These information were there over a large pile of design drawings and specification tables when constructed. Upon completion, the decay of their informational relevance begins, and gradually looses their value. This informational asymmetry must be overcome for the lifecycle control.

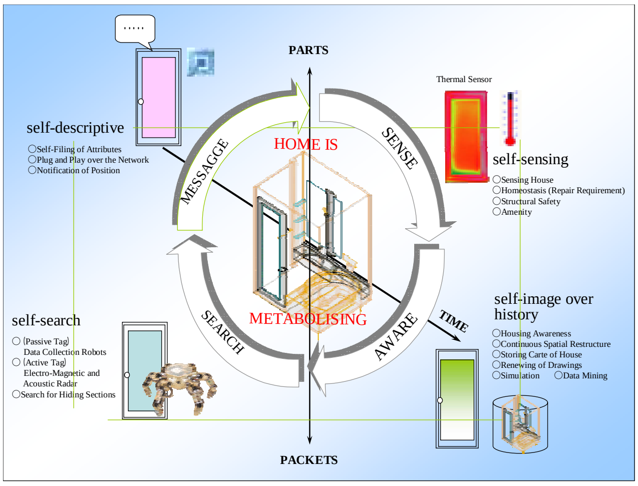

Fig.3 Ubiquitous 4+1 Housing Management System

The ubiquitous 4+1 housing management system consists of;

(1)<u>Self-Descriptive</u>: critical technology --> RFID

During the operational stage of a house, physical configuration change does not stop to accumulate via the constant interface with the occupant. When replaced or renewed, RFID-attached parts make self-filing of themselves into the appropriate data points in the active database of drawings and specification tables.

(2)<u>Self-Sensing</u>: critical technology --> Sensors

Let RFID be attached with various types of sensors, mostly primitive ones such as temperature, moisture, acceleration, or stress sensors together with so called smart sensors for the back bone- Distributed sensors everywhere over a house, which constitutes nerve system for the constructed complex. It can be then called a “sensing house”.

How a sensing house works may be illustrated by a following simple example. Houses are attacked frequently by seismic load in an earthquake prone country like Japan. In consequence, their inevitable aged deterioration may cause a threat to the occupant. A sensor which measures the characteristic frequency may be able to detect a critical state of a house, and to send a warning message of repair to an appropriate agent.

(3)<u>Self-Imaging</u> over history: critical technology --> Active Database

Sensing house implanted with a large bulk of sensing RFID supplies innumerable data with different time stamp over the lifecycle. It is of critical importance how to store the data within database over the lifecycle, given that the storing capacity of hard disk has been impressively expanded by recent technologies. Along with this line, the National Institute of Advanced Industrial Science and Technology (AIST) of Japan has launched lately a program called “Virtual Time Machine” which integrate the AIST’s existing technologies for historical data storage such as information storage to 4D virtual space (4DVM), volume graphic cluster, Bayesian Network, robust sound recognition and other relevant technologies.

It does not however suffice to store the large amount of sensing data in 4D virtual spaces. Some local judgment mechanism (Active Database) and local communication mechanism (P2P) should be implanted to initiate appropriate actions for maintaining and upgrading of a house, whose relevant logic for active database will be introduced, and called glue logic at the next section.

(4)<u>Self-Search</u>: critical technology--> Inspection Robot, Remote sensing

Under an extreme hypothetical supposition that every constituent part identified within a house among thousands or a million of them corresponds to at least one sensing RFID, it is possible in principle to constitute or reconstitute an exact “self image” of a construct, which transfigures itself physically as time goes by. It is one of the ultimate goals for the ubiquitous 4+1 housing management system to achieve an exact mapping of a physical construct into the 4D virtual space of information. The physical contents of a construct remerge as informational configuration in data via “star dust” of sensing RFID in a “constellated sky” of a construct.

However, the currently available technologies or their integrate aggregate do not reach to the stage. There are some non-negligible nuisances even for achievement of reading accuracy from RFID which are hidden deep in back space, e.g. piping behind ceilings, within hollows, and others. Let small inspection robots (spider robots) freely wander here and there within a house and read the needed information from deeply hidden RFID, passive or otherwise.

So, these are the four fundamental functions for the 4+1 management system which operate in quasi autonomous fashion. It is the third among them where the quasi autonomous *local* judgment and inductive action occur within a house. However, the local mechanism does not necessarily suffice for the entire control in practice. The +1 part of *global* judgment and action-triggering mechanism is therefore implemented as a fail-safe mechanism.

4. GLUE LOGIC AS CONTROL MECHANISM

Millions of chip implanted parts move around in a complex production system under construction. As they are assembled, their attributes become altered. After settle down of construction, these chips become the source of information for the complex construct. Some sort of control logic is required to orchestrate their movement, alteration and communication.

The control logic called "Glue Logic" is an information infrastructure which is designed to make building control easy and flexible [3]. This system binds multiple application software modules, referred as "agents", developed and compiled separately, and coordinates those agents by means of interprocess massage passing. As the Glue Logic supports event notification and condition monitoring features based on active data base scheme [4], users can easily build real-time event-driven application agents. Each agent is free from polling shared data, waiting for notification messages from the Glue Logic.

As all of the data and agents in a system are abstracted, and are handled with symbolic names defined in the Glue Logic, agents can be built without any knowledge on implementation of others. Each agent in an application system can be developed concurrently, and can be added, deleted or changed freely without modifying other existing agents. As the result of these, the Glue Logic compliant agents are easy to reuse, and the users can build large libraries of application agents. Some agents having rather general purpose may be shared among various users, the life cycle and the reliability of such agents are extended, and the cost for software development is greatly reduced. Above all told, the Glue Logic can be realistic controller for a complex control system for orchestration like the 4+1 housing management system.

As shown in Fig.4, the Glue Logic consists of two major parts: the communication interface subsystem and the data management subsystem [5].The communication interface exchanges information with agents running in both the same work-cell controller and remote work-cell controllers connected with the network system. The data management subsystem consists of also two parts: the data change monitor subsystem and the data storage subsystem. The data storage subsystem manages the association pair of the *name* and the *value* of the object. The data change monitor subsystem monitors the changes in the data storage subsystem and sends out the data change notification messages, and executes depending data evaluation.

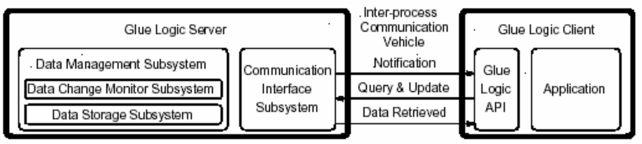

Fig.4 Configuration of Glue Logic

There spreads over the production fields from factory through construction sites as well as the complex constructs upon completion a large bulk of objects, agents, and sequencers under the Glue Logic frame. The distributed sequencers act as background prompters, which collectively control and manage the activities of the objects and application agents. The orchestrated activities make the needed jobs done autonomously and timely, passing around messages which trigger the activities of objects and agents.

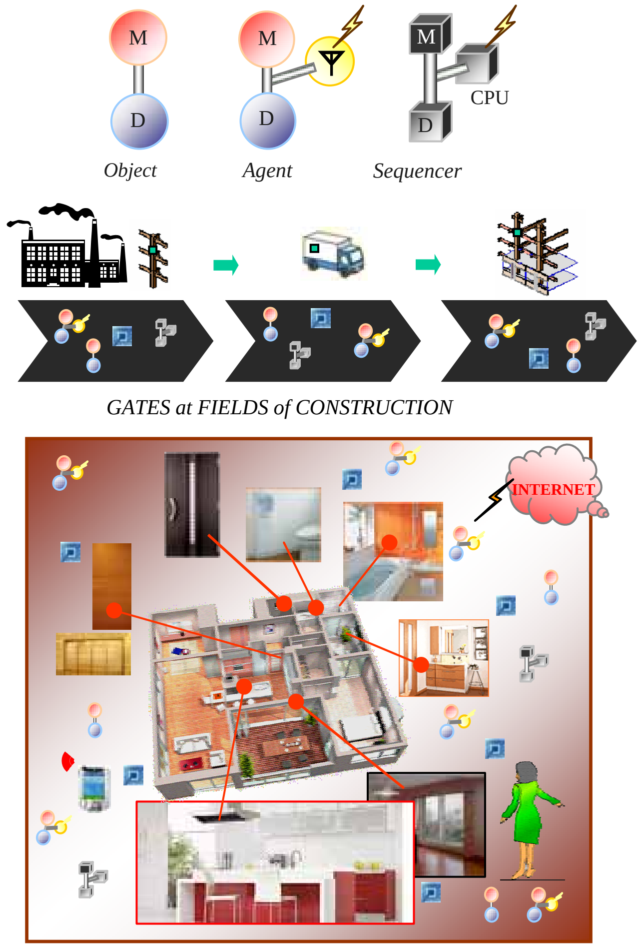

Fig.5 Glue Logic Control of Production and Product

5. UBIQUITOUS TOOLS

<RFID>

A passive type of RFID is shown at Fig.6 (right) made by Hitachi, called μ-chip. Its size is quite tiny of a micron. Attached to it is electromagnetic induction coil or antenna. When a chip-implanted part passes through a gate, the gate reads the Product URL of the part. Or utilize a mobile reader like mobile pc, PDA, or even mobile phone to read the product address or locally contained information in the part, and determines what it is, where it is, when it is as well as in what state it is. The corresponding data point in the active database equipped with Glue Logic is then altered, which generates an event and a chain of succeeding actions.

Shown at the left of Fig.6 is an active type, developed at AIST of Japan [6]. It is easily connected in wireless fashion with home electric appliances and sensors. It is a little about twice bigger than the size of button type battery, which carries a 4MHz CPU and transmission IC with about 4800bps. It is supposed to work for about 60 years in power-saving mode.

The number of chips detectable simultaneously is about 10,000,000, which makes possible a “star-dust” constellation of chips all over the targeted space.

Fig.6 Active (*left*) and Passive chips

It is expected that the size of a chip, either active or passive will be reduced down to a nano dimension even with high-speed number crunching CPU and nano actuators within a coming decade, provided that the recent quick development of Nano Technology marches on.

<Installation and Inspection>

The required points of contact for messaging are attached to each data point in the Glue Logic Controller. As the state of a building part within the data sub-system of the Glue Logic is altered as construction proceeds or the construct gets upgraded or renovated, the point of contacts are altered as well. In this way, it seems as if every building part were of autonomy to choose then- appropriate addresses and send signals to them to which its assignment is informed, as it passes through consecutive stages of life-cycle.

These assignments are sent to parts makers, telling when building parts are needed for construction or renewal, how many of them must be delivered, at where they are installed. These autonomous assignments reduce excess inventory for the makers, and superfluous temporary storage on site or off site.

Upon completion of installation of parts, acceptance inspection is conducted. A worker carries a PDF reader on whose screen page a standardized checklist pops up when it reads the Product URL from the chip. The inspection result is remotely informed to the part maker via the Glue Logic Controller. This does not necessitate inspectors from the producer to come to the construction sites for inspection.

<Virtual Representation>

Fusion of parts and packets alone opens up wide range of new possibilities never imagined before how to manage a project-type production/renovation for construction and conduct concert actions for the goals. Virtual representation of the relevant production processes and/or products embodied by parts and packets unification further enhances manageability of construction and maintenance. In 3D CAD or in 4D simulation there correspond physical chips to virtual ones implemented on software objects representing the relevant parts for a construct. The virtual chips locate off site exactly where the physical ones do on site. One can therefore walks through a construction site or a built virtually whenever one wishes, and clicks the chips on screen to let the current state of the parts on site pop up before one’s very eyes, wherever he may be, whenever he needs to. The total accumulates of production information, some limited portion of which is accessible by an individual, is now at representational integrity which makes it possible to control every detail of production processes from the off site centers. On the other hand, each activity or operation remains its autonomy in distributed fashion on site, which the ubiquitous 4+1 management system really targets for.

Fig. 7 shows an example of the screen; (1) CAD drawing which shows the installation point, temporary placement, and parts with tags, (2) package tags attached to packages of parts, (3) Product URL for a part, (4) procedural manual for parts attachments, (5) CAD details of a part, (6) web catalogs, (7) simulation for construction sequences.

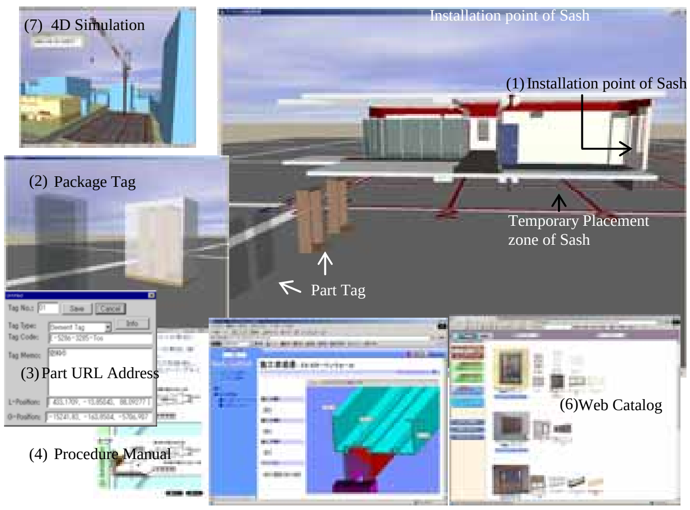

Fig.7 Virtual Representation

<Scheduling>

Scheduling is an integral complex of schedules prepared by general contractors, subcontractors, parts producers and other relevant participants in a construction project [7][8], where a master schedule is set as a global frame of all. Sources of change exist everywhere in the multiplex of schedules, lying layers upon layers, whose influence propagates within the complex of schedules at different range and speed as well as through different paths.

The Glue Logic architecture makes a dynamic scheduling possible, primarily because (1) the component schedulers are considered independent controllers of time management of their own, and (2) which send messages of requirements of schedule change to each other and respond to the others' requirements. However, it is not always possible to satisfy all the requirements of schedule change, because of possible conflicts among these requirements [9]. Unsolvable conflicts may demand remodeling of product, process, or facility (Fig.8). The Glue Logic controller switches its mode to remodeling schemes from rescheduling schemes.

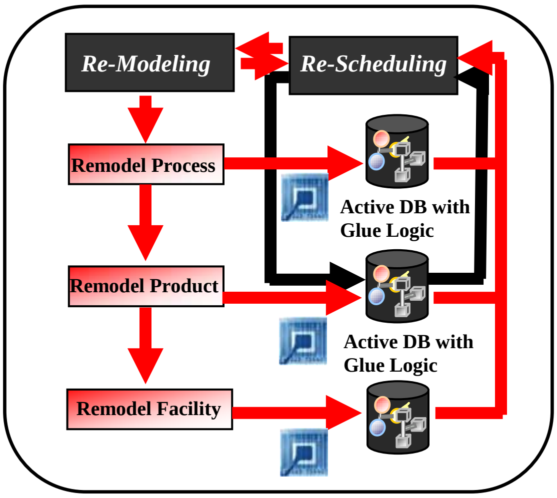

Fig.8 Mode Switching of Scheduling and Modeling

6. SUMMARY-TO CREATE, TO LIVE, TO REVITALIZE

The whole life cycle of a construct, house or otherwise, is naturally divided into three characteristic stages, construction, habitation, and renovation –coined in this paper as stages "to Create", "to Live", and "to Revitalize" (Fig.9). Although the three stages have different clocks to tick each other with different operation and development of their own, the parts and packets unification is able to restore the symmetry of operations for management so that a scalable integrated management system can now be developed.

The architecture of such integrated management system was proposed. A bulk of constituting parts is now equipped with both active or passive RFID and a variety of sensors attached contiguously or remotely, some of them carry, though low profile, a CPU. A million of RFID is now constellated within a rather compact space, a house, a building, or any construct.

Fig.9 RFID Integrated Housing Management

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