Architecture as Service (AaS) in the Internet of Everything (IoE)

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Abstract: Design as needed, and when it's needed—this is what IoE can facilitate—in particular a highly personalized adaptive architecture-as-service (AaS) meeting individual demands and expectations. This goes beyond reactive smart environments in the direction of a dwelling's anticipatory characteristics. The study addresses the potential of intelligent materials integrated via the IoE in new structures adapted to life and work circumstance of our time. Design is protected via blockchain technology and made available, on demand or according to what the context suggests, within a decentralized autonomous organization (DAO). Distributed across a large array of various devices, the ledger representing the blockchain enables digital ownership and, more important, interactions without a central control. The data informing the project was acquired from experiments in VR (as modeling medium for the future of a new kind of on-demand architecture).

Keywords: adaptive, architecture-as-service (AaS), interaction, Anticipatory Profi

User-centered (a requirement of a possible customization) and *architecture* (structuring living and other spaces) are difficult to reconcile. Once a building was conceived, reflecting what the future inhabitants expressed as their needs—different from private dwelling to office, school, research laboratory, concert hall, etc.—it is relatively permanent. Of course, homes can be remodeled to fit the needs of a new child in the family, aging parents, assistive needs of the current inhabitants. The effort is substantial, and even more so in respect to more complex structures. In the course of researching the housing needs of a particular segment of the population (Naz 2016a, 2016b)—the extremely mobile *neo-nomads*[1] encountered not only in Silicon Valley, but also in other parts of the world—it became obvious that architecture itself has to be reconsidered in view of the broad perspective of the Internet of Everything (IoE), usually reduced to the subset of the Internet of Things (IoT). Indeed, the enabling capabilities of smart materials (Rogers, Barker, Jaeger 1989) associated with increasingly available computing resources, together with the ability to achieve full connectivity encourage rethinking even in the most traditional activities. Architecture, at the origin of design, is such an activity, still resulting in brick-and-mortar or adobe rigid structures, expensive to build and maintain. Of course, they can be made "smart" through a variety of means and methods; but a smart structure still does not afford a perception of the living space conducive to individualization. There is no adaptive dimension to architecture, whether in its traditional forms or is more recent developments that allow for a modicum of interactivity. And this despite the realization that the occupants of the space go through change in many ways. Expressed otherwise, their Anticipatory Profile™ (Nadin 2012) changes, but the space in which they live and work reflects only the reactive component of their life (e.g., pull shades down, turn on the lights).

In order to understand why a new concept of architecture, grounded in IoE or IoT thinking, is relevant, we examined the three-part formula of GoogleX (the "Moonshot Factory," as it is also called):

1) It must address a very large problem
2) It must propose a radical solution.
3) It must employ a relatively feasible technology.

1. The Problem

If it were only for the neo-nomads, their needs for housing will eventually be met (even though at ever higher prices, and to the detriment of those who cannot afford such prices). The problem of housing is huge. This pertains to the criterion of addressing a very large problem. While the entitled class can afford the oversized McMansions, a large segment of the world population still lives under circumstances no one can be indifferent to. If we could conceive of housing units that provide conditions for healthy living, we could further foster quality of life by engaging computational resources in endowing such housing units with not only "smartness" (from control mechanisms of all kinds, to predictive procedures such as energy management), but also with adaptive capabilities reflecting the changed anticipatory profile. Those who work from home, neo-nomads active in the digital economy, and any other professionals could benefit from a living environment in which the perception of space drives the adaptive features: color, texture, light, sound, contrast, for example.

Initial research in a virtual environment that emulates such parameters (Naz et al. 2017) provided preliminary data (see 4.1.1 and 4.1.2). Further research, expanding into the topology of real space endowed with variable features provided additional data (see 4.1.3). The data is significant in understanding the problem, as well in relation to the implementation of a new concept of architecture: architecture as service.

2. The Radical Solution

Incremental innovation, often more formal in architecture than in other human activities, cannot satisfactorily address the problem sketched above. The possibility of a radical solution is associated with the opportunities of the next platform technology. Moreover, the data suggests that what once was the permanent solution—the architecture of dwellings meant to last forever (or at least give the illusion of eternity)—begs for an adaptive alternative. Smart environments were a step in this direction. But we can go even further, making architecture itself smart, i.e., transcending the reactive aspects of space interactions in favor of anticipation-based solutions. Therefore it is time to

[1] For a definition of Neo-nomad, see D'Andrea A (2006) Neo-nomadism: A theory of Post-Identitarian mobility in the global age. Mobilities 1(1):95–119; and Abbas Y (2004) Neo-nomads and the nature of the spaces of flows. In: Proceedings of UbiComp in the Urban Frontier Conference, pp. 12-13.

reconsider architecture. The outcome should be decentralized architectural service that allows for accommodation of continuously changing needs. The same space can be reconfigured on-the-fly, under the assumption of connectivity and almost limitless computational availability via the cloud. Of course, this view also reflects the need to understand sustainability: adaptive architecture consumes fewer resources. What the “new architect,” i.e., a decentralized service provider, makes available is intelligent design driven by needs as they arise. Thus AaS precludes the on-the-whim choices of playing with the space, unless the space itself becomes a medium for some not yet defined new types of games. In a nutshell: within a blockchain architecture, we would enable the integration of sensor data, intelligent materials that can adapt to new circumstance, and architectural principles inspired by the adaptive characteristics of life.

Datamining endows the structure with a learning capability (evidently, learning as in machine learning in its variety of implementations). Learning itself can further inform architectural choices within the entire IoE where the service is made available. The blockchain is also the guarantor of the integrity of the process, including the rights of those who conceived the architecture, served on demand, and the primary rights of the inhabitants. This is an example of humanized computing that reflects awareness of sustainability, not in words but in concrete sustainable living structures. It is way more sustainable to adapt a space to continuously changing needs and requirements than to rebuild or renovate. Within AaS, there is no rebuilding or renovating.

3. The Feasibility Aspect

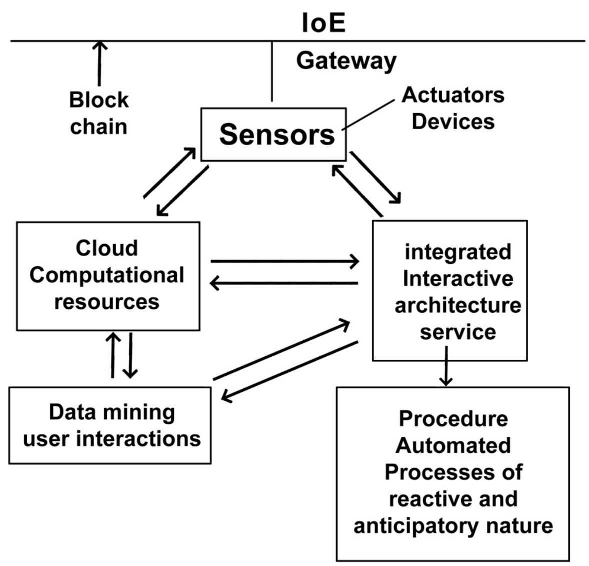

Fig 1 IoE as backbone for AaS

The diagram (Figure 1) does not fully reveal how the IoE is the backbone of providing architecture-as-service (AaS). More specifically, all devices—displays, sensors, effectors in the intelligent materials, etc.—are certified to trade resources. Data is securely stored and verified on the ledger. The ledger is distributed over a large array of devices. Thus ownership and exchange are assumed without any central control. Without going into details, here are some features: a service layer (for management of the integrated architecture deployed); application layers; and by necessity, more than one connectivity layer (Table 1). The currently available technology—Wifi, LoRa, Bluetooth, as well as Web protocols (HTML, XML, JSON, etc.)—is such that feasibility can be achieved—although not without some difficulty.

Service layer	device management (can be a Web application)
Application layer	share data with multiple users
Transport layer	IoT
Connectivity layer	current protocols (Wifi, Bluetooth, etc.)

Table 1 Layers of the network infrastructure

The IoT currently developed is an extended vertical dimension for network infrastructure. It will have to be adapted so that it can support transactions, probably cloud-based for “smart” walls, “smart” windows, “smart” sound environments, etc.

The open source infrastructure of our time will have to support blockchain service architecture modules. The intellectual property of AaS providers is just as worthy of protection as that of the persons who will live and work in adaptive spaces, fulfilling changing needs and, eventually, demands. The relatively odd examples of connecting everything (IoE) via the Universal Sharing Network (USN) are not to be dismissed. In the new space, everything can enter into transactions: the computer acquiring a new operating system or access to some software; the refrigerator ordering service and even restocking of groceries; the window to the world getting a new view, or disappearing altogether.

4. The Data

A minimum of built, or fabricated, space, with variable perceptual qualities) can serve as a module (Figure 2). It will be endowed with all facilities (pertinent to health and well-being) provided in association with an adaptive living/working/leisure/recreational space. Perception of space and of sound is interrelated. Therefore, in order to generate different architectural perceptions, in addition to changes in texture, color, contrast, the sound characteristics of the space are also subject to control.

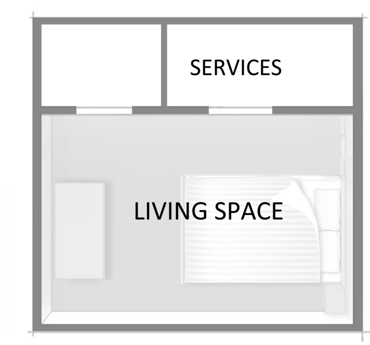

Fig 2 Conceptual sketch of a module

While the neo-nomads and their specific needs initially informed the project (Naz 2016), data acquisition was intended as a premise for conceiving AaS: perception-driven variable spaces of optimal individual and social expression. Of course, an inhabitant can hang a painting on a wall, or can recall any image from his or her collection, from museums, from friends who share such images. The same holds true for sounds—playing preferred music, or creating an ambient sound—whose perception, as suggested above, is modulated in relation to that of the space. The "virtual" window or skyline is part of the service delivered by AaS embedded in the IoE, either in the form of video streams or as images that intelligent materials (see 5.3) synthesize on demand (Pereira et al 2010).

It should be noted that the experimental base for this description is larger than one can expect. Almost 50 years ago, Frei Otto and Kenzo Tange[2] conceived Arctic City; shortly after, Cesar Pelli came up with the large-scale Urban Nucleus at Sunset Mountain Park[3]. In continuation of the obsession with doomsday, many attempts were made to provide an architecture of survival to people with wealth or power. From the viewpoint of this study, this is relevant for solutions already available: cover energy demands by harnessing solar and wind power; find environmentally friendly solutions to treat waste and sewage. These and similar features are currently deployed.

4.1 Adaptive architecture variables

Sensory data related to color, texture, and materiality, as well as form and shape, is associated with psychological and physiological feelings of beauty, comfort, or pleasure. To create adaptive, meaningful spaces is to understand the extent to which various architectural design parameters individually and collectively impact emotional responses. Specific psychophysiological variables associated with the perception of pleasure and comfort, feeling of warmth, coolness, spaciousness, intimacy, excitement, or calm are subject to non-intrusive influence via characteristics of space (including sound).

Perceptual studies were conducted to generate data that can establish correlations between design parameters and perception of emotional aspects of architectural spaces. Data was gathered in two phases. Phase 1 was a user study conducted in a virtual reality system consisting both quantitative and qualitative research. Phase 2 was an online survey with computer-generated renderings.

4.1.1 Quantitative study

In phase 1, a user study was performed in a living space simulated in a 6-sided immersive CAVE-type virtual reality system in order to examine emotional responses to perceived spatial experiences. A set of virtual spaces was constructed with adapted equivalent design parameters of color, brightness and texture. Participants were asked to rate each of the virtual spaces quantitatively through a set of answers to questions focused on the architectural characteristics. Emotional responses were examined in several categories represented by pairs of oppositional adjectives: warm and cool, spacious and intimate, exciting and calm, as well as perceived comfort and spatial preferences for specific activities.

Data analysis performed a mixed-design factorial ANOVA with three repeated-measures factors and one between-subjects factor. IBM SPSS 24 was used for analysis. Data was considered statistically significant at $p<.050$. Data analysis revealed a significant main effect of color, brightness and their interactions on perception of specific psychophysiological aspects of spatial qualities. Orange (a color from the warm end of the color spectrum), was perceived significantly more *warm* ($F(1,30)=153.162$, $p<.001$), *exciting* ($F(1,30)=22.087$, $p<.001$), *intimate* ($F(1,30)=4.960$, $p<0.05$), *comfortable* ($F(1,30)=31.772$, $p<.001$) and more preferable for *resting* ($F(1,30)=10.732$, $p<.005$) and *working* ($F(1,30)=10.247$, $p<.005$) than blue (a color from to the cool end of the color spectrum). On the other hand, blue was perceived as significantly more *cool* ($F(1,30)= 97.117$, $p<0.001$), and *calm* ($F(1,30)=4.918$, $p<0.05$) than orange. Bright spaces were perceived to be more spacious than dark spaces ($F(1,30)=5.615$, $p<.050$, $\eta^2=.158$), as shown in Figure 3. Significant interaction effects were also found between brightness and texture on certain spatial aspects.

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[2] For an idea of the project, see http://socks-studio.com/2015/10/03/the-artic-city-a-project-by-frei-otto-and-kenzo-tange/

[3] See: http://www.architectmagazine.com/technology/cesar-pellis-1966-urban-nucleus-p-a-award-winning-plan_o

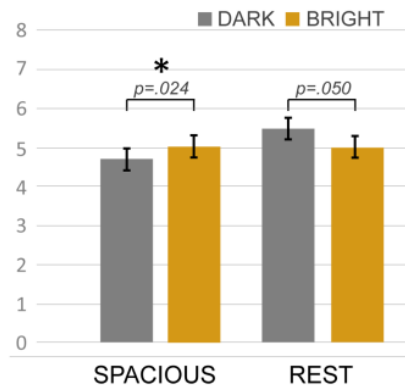


Fig 3 Brightness effects. Error bars represent standard errors

4.1.2 Qualitative study

In the second part of the virtual user study, a qualitative research study was conducted with open-ended questions in order to find correlations between perception of spatial qualities and corresponding design modifications suggested by the users. Inferences were drawn by assigning themes to user responses in order to derive design suggestions from participants with regards to the following categories: warm, cool, spacious, intimate, exciting, calm, comfortable, as well as muted and saturated spaces. Muted (soft) and saturated (vibrant) were two additional psychophysiological spatial aspects related to color perception.

The data analysis revealed that users preferred modification of surface color in order to create perceived feelings of *warmth* or *coolness*. 67% of the participants who asked for color modifications preferred warmer colors (variations of red, orange, yellow or brown) for comfort. Color was also inferred as the primary design parameter the users suggested to modify in order to create muted or soft environments. A number of users wanted to modify surface texture and color in order to create more exciting spaces. 67% of these users desired interesting texture, visuals, painting, surface details, or decorations. 33% users asked for brighter or more colorful surfaces.

The study also revealed that participants associated brightness levels, degree of openness and aesthetically pleasing exterior views to comfort and feelings of spaciousness. 46% participants suggested an increase in the brightness level in order to increase the perceived feeling of spaciousness. Among these participants, 39% asked for increased brightness with the addition of windows, exterior views and natural light (Figure 4).

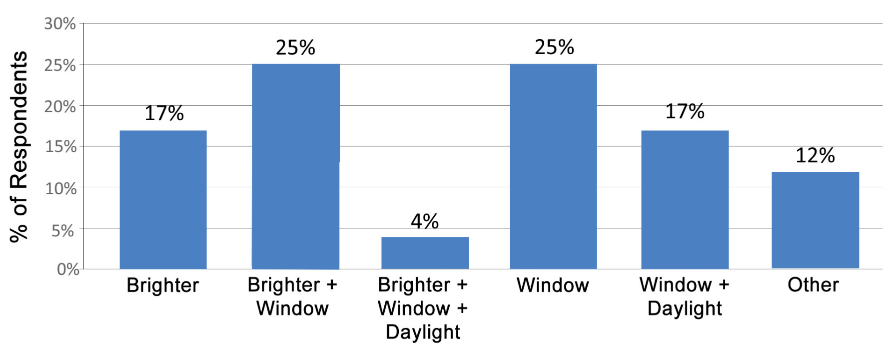


Fig 4 User recommendations for *spaciousness* include openness and illumination

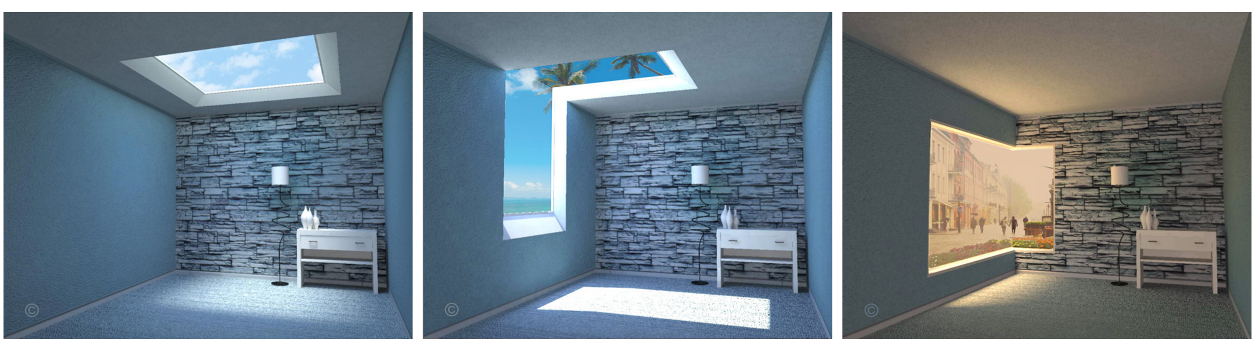
4.1.3 Online perceptual study

A perceptual study was conducted online to investigate further the perception of comfort in a living space by introducing specific architectural design features related to *spaciousness*. The study introduced a virtual window in the living space and quantified the impact of its design parameters on user's emotional responses. Data generated from this study can further help formulate aesthetic guidelines for adaptive comfortable space creation. (Suffice it to imagine that the window position and the view afforded can change.)

The study analyzed the emotional impact of the characteristics of the window (shape, placement/location, exterior view) as well as illumination of the interior space. The interior space used three window shapes—square, elongated rectangle and L-shape (figure 5)—each positioned at three different locations: on the ceiling, on the wall and combined (ceiling and wall). Three exterior views were displayed for each window shape: a large-scale ocean or sky, a medium-scale green expanse and a small-scale street or city view. There were three lighting conditions: early morning, midday and sunset. Figure 6 demonstrates three images from the experiment.

a) Square-shape b) Rectangular shape c) L-shape

Fig 5 The three window shapes



(a) (b) (c)

Fig 6 (a) Window *shape* = square, *location* = ceiling, *view* = sky, *illumination* = early morning. (b) Window *shape* = elongated rectangle, *location* = ceiling and wall, *view* = ocean, *illumination* = midday. (c) Window *shape* = L-shape, *location* = wall, *view* = city, *illumination* = sunset.

Data analysis revealed the following:

4.1.4 Shape preference

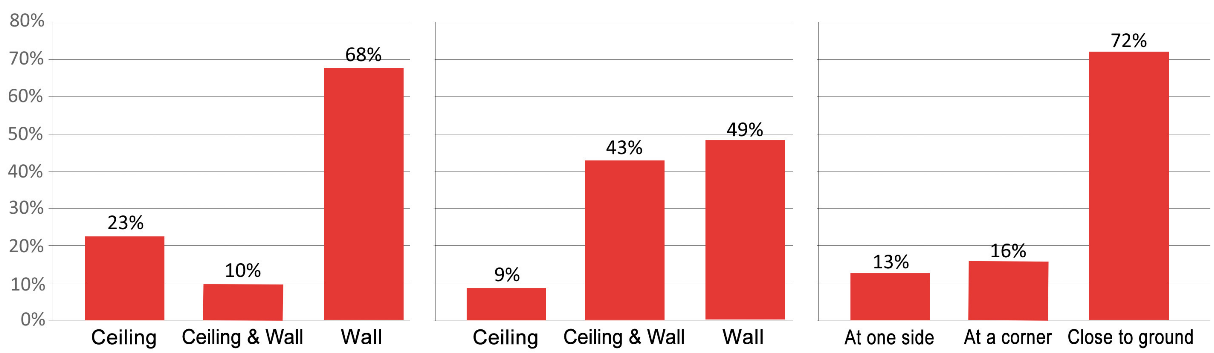
Data analysis revealed that the elongated rectangular shape was preferred by most participants (36%). 33% respondents preferred the L-shaped window and 31% preferred the square-shaped window.

4.1.5 User preference: window location

For each window shape, most participants preferred to place the window on the wall (Figure 7). Figure 8 shows that the wall location was preferred by 68% participants who selected the square-shape window, 49% participants who selected the rectangular window and 72% participants who selected the L-shape window.

a) Ceiling b) Ceiling and Wall c) Wall

Fig 7 Three *locations* for *shape* = Square



a) Square b) Rectangular c) L-shape

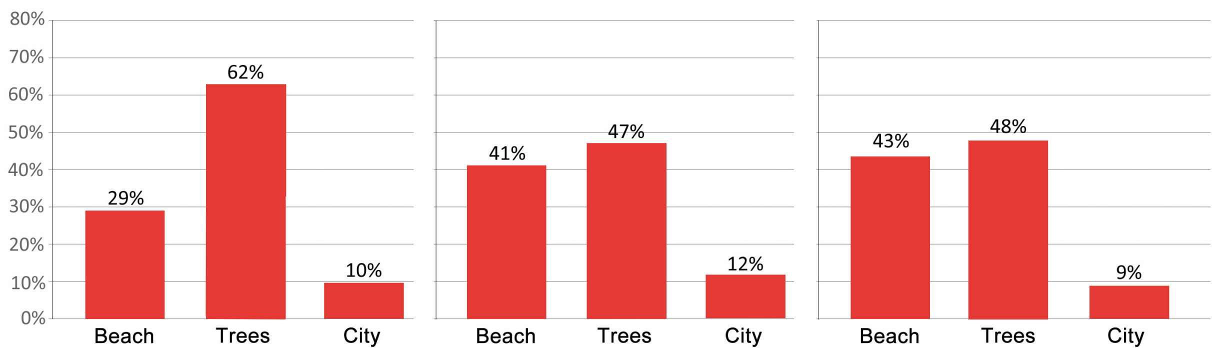
Fig 8 Preferable window locations for each shape

4.1.6. User preference: exterior views

For each shape of windows located on the wall, most participants preferred the exterior view of a green expanse (Figure 9). Figure 10 shows that the natural view with trees was preferred by 65% participants who selected the square-shape window, 47.1% participants who selected the rectangular window and 47.8% participants who selected the L-shape window.

a) Square-shape b) Rectangular shape c) L-shape

Fig 9 Most preferred exterior view: The green expanse (with trees)

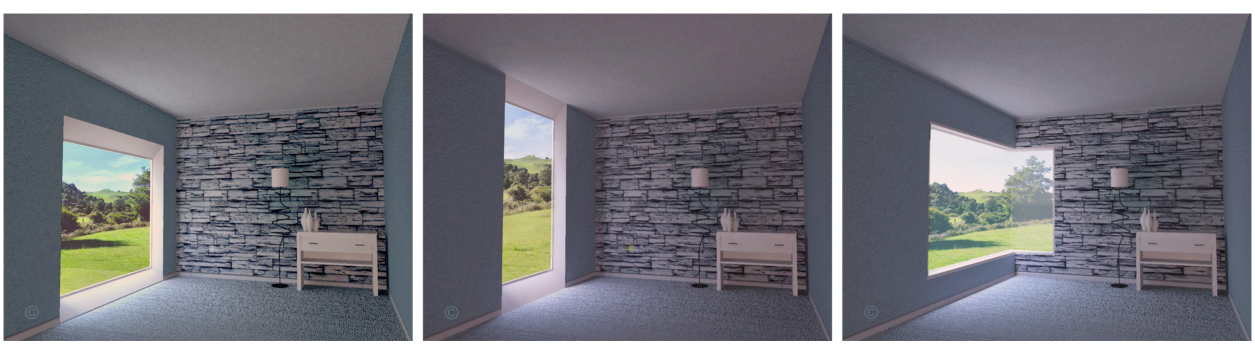


a) Square b) Rectangular c) L-shape

Fig 10 Preferable exterior views for each window shape located on the wall

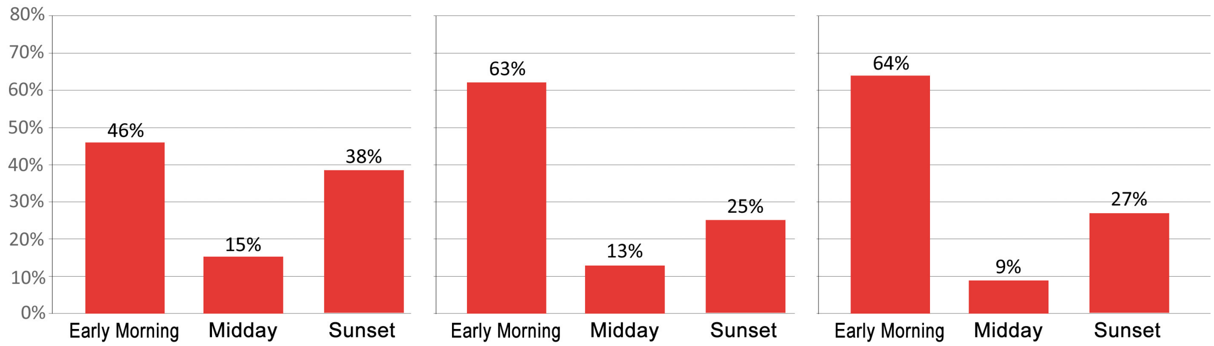
4.1.7 User preference: illumination

For windows of all three shapes located on the wall and with a view of the green expanse, most participants preferred the lighting condition of early morning (Figure 11). Figure 12 shows that the early morning lighting condition was preferred by 46% participants who selected the square-shape window, 63% participants who selected the rectangular window and 64% participants who selected the L-shape window.



a) Square-shape b) Rectangular shape c) L-shape

Fig 11 Most preferred lighting condition: Early Morning



a) Square-shape b) Rectangular shape c) L-shape

Fig 12 Preferable lighting condition for each window shape located on wall with a view of the green expanse with trees

4.2 Summary of results

Data analysis aimed at understanding how architectural parameters can be adaptively changed revealed elongated rectangular shape was preferred by most participants while the square-shape was preferred the least. Participants preferred windows to be located on the wall with an exterior view of trees and greenery. The most preferred lighting condition was early morning light that had softer illumination and shadows. It could be noted that culture plays an important role in participant's aesthetic preference for window shape and location, as well as perceived feeling of comfort. AaS will have to integrate such knowledge in the procedures deployed via the IoE.

5 Implementation Elements

5.1 Image Storage

Multimedia technology advanced to the level at which either video streams or any other form of images can by stored. In the IoE, even the intelligent materials of the architectural variable structure can serve simultaneously as medium of storage and display. The properties of such materials are also subject to adjustment. The embedded AaS as an intelligent procedure has access to an appropriate indexing facility. Either the inhabitant of the space or the Intelligent Management of the Space (IMS) can initiate changes, for example: "Night with moon and stars;" or, when appropriate, "Stormy night." Even situations that make little sense (e.g., snowfall in August) can be considered. AaS serves as a dialog partner, not as a censor. Current indexing and retrieval of semantic image context uses conceptual graphs. If the choice is for live video, real-time systems would be activated.

Real-time simulation is also an alternative (requiring an appropriate multicast protocol). Given the fact that image resource management is relatively difficult, it is highly possible that cloud-based platforms will be a more practical avenue. In this case, the Hadoop file System (HDF) would be a good place to start. This solution was tested (Kou, Li, Zhon 2016) as a simulation that comes close to AaS requirements. Updating video files or any other image generation procedure takes place under the assumption that services do not terminate.

5.2. Emotional State Assessment

This is yet another challenging aspect of implementation. Clearly, there is no classic Human-Computer Interaction (HCI) involved in the adaptive behavior of the space. Still, the H factor remains the most important aspect of AaS. The large space of variables (physiological data, social data, cultural data, etc.) makes it difficult to deal with all the aspects involved in defining a need, a desire, a request. Of course, the nature of the activity—reading (a book, magazine, e-book), programming, sleeping, having a conversation, etc.—is definitory for how the space adapts or remains the same (Bermudez et al. 2016). The need for continuity is probably as telling as the need for adaptive change.

In this section, we shall make reference to the emotional state and how it can be assessed in such manner that underperformance (ignoring important factors) or over-performance (an "overactive" architecture) are avoided. Within the HCI model, a machine is supposed to identify and eventually react to what is deemed as emotions (represented by data, such as change in face color, dilated pupils, sweating, raised voice, choking, etc.). Ideally, the machine would estimate emotional aspects with no less a degree of accuracy than a person does (Cominelli 2017).

Within AaS, there is no machine in that sense, but an integrated digital processing variable configuration on a ledger. Here we deal with a space endowed with sensorial capabilities, with effectors that contribute to its variability, with display opportunities (among others), all integrated via an intelligent procedure that outputs adaptive living and working environments. To identify emotions via factors such as blood characteristics, brain activity, types of motoric expression (e.g., abrupt, smooth, continuous movements), voice expression (pitch, speed), vocabulary, and facial expression is not a goal in itself (as it is in medical applications). The target is the perception of the living space as the unity of a given built or fabricated structure and virtual factors. In some ways, the perceptual drives the perceived variability via architectural choices informed by aesthetic consideration (Nadin 1995).

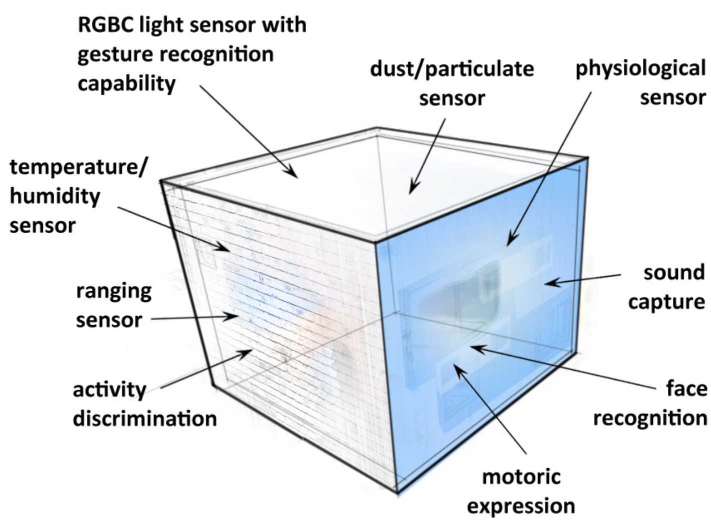


Fig 13 Sensing, actuating, and control engineering in AaS

5.3 Physical embodiment

This is not the place to provide an in-depth review of what is known as intelligent materials. Suffice it to state that it is not the material as such that is intelligent, but rather that variability of properties—reflection, refractions, touch/texture/feel/, temperature—can be intelligently achieved as the context requires. The classic definition (Rogers, Barker, Jaeger 1989) is general: "…materials which sense any environmental change and respond to it in an optimal manner." Of course in our days the "smart" aspect reflects progress in synthesizing materials with interaction capabilities, some based on the knowledge acquired in the production of nano-materials. The possibility of fabricating a living space or a work space with such materials is considered for small projects. Our attempt to integrate such materials in housing for the neo-nomads made clear that data management (in both the acquisition phase and the control application) is probably intense to the level of Big Data management. More recent reports on "intelligent materials" Hanselka, Nuffer (2009) argue in favor of creative applications through "adaptive assimilation to actual environmental conditions." Sensing, actuating, and control engineering (Figure 13) are emulating biological processes. We are only at the beginning of many promising avenues that lead to actual "smart" environments.

An example of a smart window best suited for adaptive spaces is the CoeLux, an artificial sky that brings the effects of natural light inside interior spaces (Figure 14). This LED lighting system simulates the Rayleigh scattering of sunlight in the atmosphere to produce the illusion of diffused solar radiation from a distant light source and the blueness of the sky ("Switch on sunlight" 2014). In a few millimeters thick optical system, nanoparticles (including titanium dioxide), are arranged in varying size, density and composition in clear polymer calibrated to replicate the different wavelengths of sunlight (Bain 2015). The system can emulate a range of "warm" and "cool" light and shadow conditions from different climatic zones around the world.

Advances in nanotechnology and smart materials offer new possibilities for space design. Materials can potentially shift from one state to the other in terms of appearance (color, opacity or illumination). Transparent glass with nanoparticles arranged in thin, clear polymer layer can produce various organic, reflective and fluorescent head-ups displays with a wide viewing angle in potentially low cost (Chandler 2014).

Smart glasses with electro-chromatic technology have adjustable opacity levels that respond to illumination and temperature changes. In programmable building surfaces, such technology equipped with photocells and sensors can control transparency levels in response to movement of passers-by in order to maintain privacy (Telhan 2010).

Fig 14 Application of CoeLux (image source: www.coelux.com)

As data flow and control process overview indicates, AaS takes advantage of rapid progress in the invention and production of large material surfaces that can either "synthesize" an image with desired characteristics, or serve as a projection background with relatively high performance (i.e., low-cost display with long duration properties, easy to maintain or to replace, when necessary).

5.4 The ledger

The IoE (of which IoT is a subset) is the expression of interactions among processing units, sensors, materials with variable characteristics that can be modulated by needs and demands, and by persons living and working in the variable adaptive space. A great variety of data types and control processes are integrated.

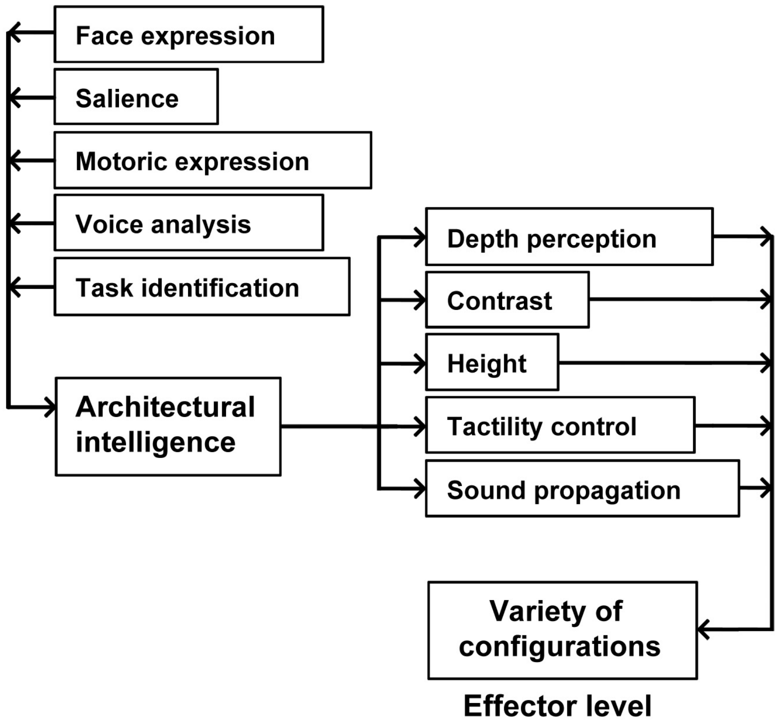


Fig 15 Data flow and control process overview

5.4.1 The need for an ontology of the IoE service

By necessity there is the need to provide an ontology pertinent to the AaS. Examples in pseudo-ontology description without the hyperlink to detailed descriptions include:

- actuating element: effectors changing properties of walls
- attribute: what is subject to the IoE provided architectural service
- metadata the variety of data acquired in the variable architecture configuration

In order to "understand" the data representing the variables in the adaptive space, the AaS application has to be based on a comprehensive ontology that is actually confirmed within the blockchain. Transactions are continuously "time stamped," i.e., the mining aspect of the blockchain (in the example we chose) maintains the integrity of the process within the IoE.

In the absence of such an ontology, the entire programming effort is undermined by the very complicated relations among the architectural and the perceptual variables. The ontology will have to detail interpretations of data pertinent to what is done in the space and how the inhabitants' condition affect architectural choices.

5.4.2 Procedure for providing the ledger

Haber and Stornetta (1991, 1997) came up with a ledger structure meant to be a repository, or a "digital notary" service. This was important for patent claims, for contracts, and for transactions involving values to be protected. From this initial attempt, very many applications were derived, the most visible being the cryptocurrency (in particular, the Bitcoin). Without going into detail, we want to point out that the data structures proposed, and since then actually deployed, simplify the handling of contracts: signatures are replaced by hashes; various components can be grouped into batches or blocks, each properly time-stamped; and binary trees of hash pointers replace the linear successive chain of demand and executive cycles (Narayanan, Clark 2017).

From the perspective of providing a service, AaS can only benefit from such structures. There is no central authority; the architect is actually a procedure for providing, as a service (Stapelkamp 2017), the design based upon which the living space is adapted to perceptual expectations. These are continuously revolving; some can be replicated from one situation to another, or over the IoE. Others are rather unique. Each has to be validated in the blockchain (Figure 16).

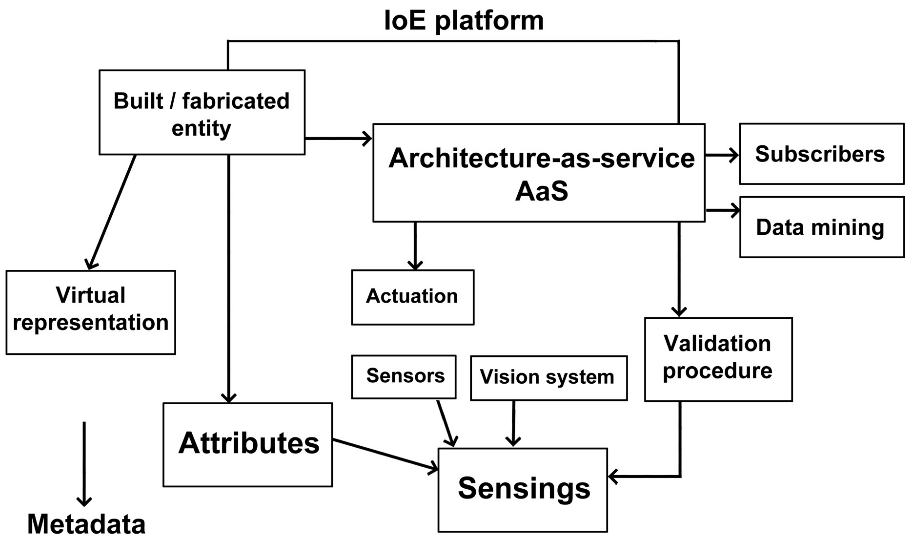


Fig 16 Internet-of-Everything (IoE) for Architecture-as-Service (AaS)

In the AaS, there is architectural expertise encoded in a variable knowledge domains—the system learns from various situations it has to address—and there are situations that can easily be transferred from one adaptive dwelling to another. Not unlike buying electricity or some cloud services (storage, access to programs), the end user enters a sui generis contract for being provided with the architecture optimally suited to his or her activities, lifestyle, etc.

Proof-of-work instance prevents abusive behavior (from inside and/or outside the AaS), including those that might affect the integrity of the integrated system. Moreover, the architectural activity, most of the time autonomous (rule-based or driven by deep learning, i.e., convergence), but always involving the creativity of living architects and the input of those benefiting from AaS, can be compared to that of the miners—solving proof-of-work, i.e., coming up with architectural solutions—from cryptocurrency. Our choice is based on a transactional system—such as Ethereum, but not limited to it—within which individuals (tenants or architects) get involved in secure interactions (Buterin 2015).

The system we considered is one among those under current development. Obviously, more such blockchains will emerge, offering to the IoE options that not long ago were just not available. In the past, the centralized structure assured trust, through a third party, of at least trust between the two parties involved in an activity (service provider and client). What is created within the blockchain is a shared state, which is embodied in the state machine. Architectural service involves a great number of transactions, which constitute a chained block system.

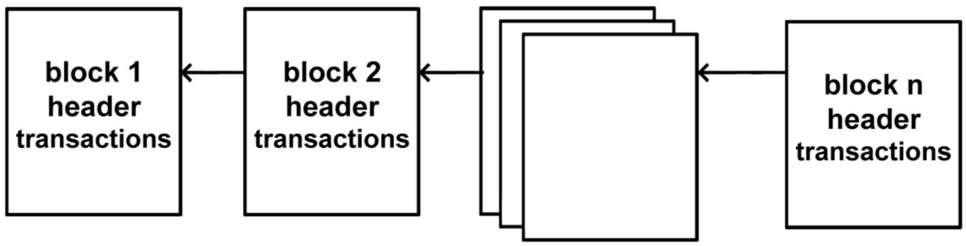


Fig 17 Ethereum: like-chained block transactions

Transitions from one state to another (NEXT) are validated. Validation is where the so-called mining aspect comes into place: within the IoE, blocks are initiated as the "state" of the "living space" changes. Validations means: processes that evaluate whether the change makes sense. An intelligent architectural procedure processes blocks from the entire IoE, where adaptive architecture is deployed. Most of the time, the architectural service will result in multiple paths: the same space can be readjusted for a perception of brightness, spaciousness, intimacy, etc.

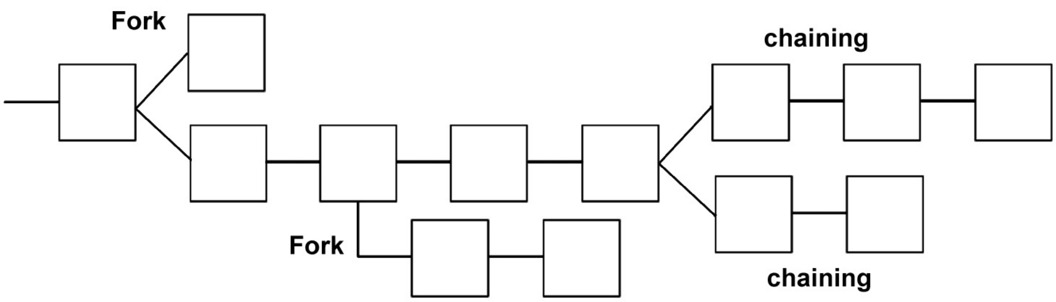


Fig 18 A path is validated when the transaction is approved, via private keys or contract code.

We would not enter into details of the Ethereum state and its components, or in the description of the tree structure used to store transactions and receipts. But given the novelty of the suggested application, we prefer to explain how the AaS actually works within the IoE (under the assumptions of using cloud-based computing resources). Essential are the decentralized applications. But AaS is no a counter for secure payments (such as the Bitcoin Counter). It provides the means necessary to allocate resources to a specific architectural task. A decentralized application is service that no single entity operates. To provide a video stream in a window is not an AaS application. The integrated service is based on competing applications. If the adaptive space is used for sleep, the competition is among applications that control light intensity, texture, resource management for the window display (LED or some alternative based on nanomaterials). The Ethereum protocol is such that decentralized applications contribute, via IoE, resources for the AaS. Nobody really controls the architecture. The "landlord" is made up of the community of tenants and architects who together constitute the AaS.

In the perspective of time, IoE will expand, and competing architectural ideas will emerge. This will benefit the tenants through more choices and lower prices for the architectural service. The blockchain technology actually becomes a particular form of asset management: each living environment is an asset whose characteristics need to be augmented as necessary.

The intelligent property aspect of AaS becomes a particular application of the blockchain: preserve the value of architectural solutions and provide the means for rewarding the authors (inspired by Catlow et al. 2016). Maybe Nick Szabo's (1996) idea of smart contracts could be applied here since it provides automated enforcement. A permissioned blockchain places restrictions on those who are entitled to join AaS. For instance, the medical profession might seek access to data since it could trigger new forms of remote diagnosis. This can change the block sequence since the FORK of derived applications triggers new instances o certification, but also competitive bids. Trustworthy participants could come up with other applications, thus increasing the value of the entire decentralized structure. This, of course, will raise issues of scaling. But this is a different subject, deserving more attention than can be given here.

6 The Problem of Scaling

As usual in the case of technological advances, nothing is free. The entire decentralization (which the ledger facilitates) entails requirements that limit choices. For instance, the problem of scaling proves very important—but not yet solvable. Every node on the IoE actually processes every transaction. Moreover, copies of transactions (the entire state) are kept. The protocols deployed so far (Bitcoin, obviously, is the most advanced, but also Tendermint, Ripple, for instance) confirmed that decentralization provides fault tolerance, security, and autonomy. The more nodes added, the lower the performance of the resulting "meta-machine." Internode lateness increases quickly. This is not very important for architectural variability; but with associated functions, such as medical supervision, it can become relevant. This is not the classic case of database-driven performance, where one can increase the number of servers. Here the expectation is to increase the computational throughput of every node. But in a public configuration of nodes, such as in an IoE-based AaS, this cannot be easily solved. For the time being, limiting the number of nodes seems the only option. If AaS should be adopted, every party involved—architects, technologists, tenants, etc.—would have to work towards defining the compromise between performance and feasibility

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