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SYSLOOP: AN ALLOPOIETIC ENVIRONMENT AGENCY

KAREL PÁNEK
NUVIT (National Institute for Innovative Technologies Research)
EMPYREUM Information Technologies
SYSLOOP

MARIE DAVIDOVÁ, MArch, Ph.D.
Collaborative Collective
Technical University of Liberec – Faculty of Art and Architecture

ABSTRACT:

Unlike preceding “autonomous house systems” sysloop is cross-layered and highly scalable concept of “allopoietic system”, a system that is autonomous though dependent on the exchange across its environment (Dekkers 2015). This is performed through three types of co-design: • co-designing of trans-disciplinary co-authors; • co-designing of environment from which it is learning, users included; • co-designing of artificial intelligence and big data. At the scale of local environment, sysloop is focused mainly on interrelations of individual life space qualities, providing contextual autonomous behaviour across many aspects such as climate, light, sound, smell, safety, access control, etc. Due to such scope, the trans-disciplinary team of experts developing sysloop technology is evolving in time in reference to related fields. We specify key aspects of an alternative information system with ability to make decisions based on automated interpretation of meanings, instead of (conventional) symbol processing. We verify such information system in practice of environment automation, introducing technological support of overlapping values such as information hygiene, lifelong learning, aesthetics, overall comfort, etc. Such environments are integrated at “buildings” units scale in phenomenological terms and at “industrial” units scale focused on adaptive automation and reliability engineering, both processing micro-sensorial data and performing qualified decision making in real-time. These together with other big data available are integrated to support the “cities’” scale layer. This layer is to serve for informed city planning and emergency situations solutions, including automated, personalised assistance to individual citizens, etc. This multi-scaled system is feedback looping across its layers of scales and types of co-design and thus evolving by data and most importantly, its ever-changing relations. It gives to the term “smart buildings” its meaning across the scales towards sustainable development, performance and ecosystems. The authors, among all the team, built the first prototypical family and office building for real-world testing and further development. This “real life co-design laboratory” is elaborated at separate paper for this conference.

INTRODUCTION:

In this section, we explain how longstanding common leaning to a fixed structure affects ways of processing information and why it limits advancement towards automated decision-making and what are the implications in order to overcome such limitation. The necessity of organised describing of reality led to concept of a paper form. The paper form has been, until today, across many fields of human activity, considered a convenient method of gathering and storing information. By no coincidence paper form digital equivalents – a relational model (Codd 1970) and a spreadsheet application, i. e. VisiCalc, 1979 (Licklider 1989), emerged at the beginning of personal computing era. Enormous simplicity, capacity and proliferation of this concept shaped the paradigm of individual thinking about information and its processing in general. Despite an extensive advancement across all fields of computer science for almost five decades, the digital equivalent of paper form prevailed and supported common notion of how information should be collected, stored, communicated and processed within information systems.

The relational model has inherited and is based on prerequisite of a fixed structure. As with columns in spreadsheet document, the structure of data in view (i. e. attributes of certain group of objects) must be defined in advance and kept ever after. Common effort of the user and integrator to define data relations of interest in advance then leads to typical tendency (from the integrator's point of view) to unify and (from the user's point of view) to confuse the way of distinguishing and classification (technical representation) with the way of displaying (visual presentation). Within relational model design, an information system not only adheres to fixed structure of data, but also inevitably to a fixed set of methods of its processing. Technically, due to the fixed structure, these systems tend to offer just matching, filtering and sorting operations, combined with elementary statistical tools. Practically, the result of such effort is usually a system that just displays data. Due to these limitations, such systems are predetermined for temporary single-purpose use only and for emergency redesigns in future, whenever internal or external conditions change.

Figure 1: Construction site of an experimental building representing a prototype of proposed system. (photo: Pánek, 2013)

Foremost the relation model handles data through symbols (i. e. names of columns or values in rows), it does not cope in any way with actual meanings of things. However, the value of information does not lie in its existence but in its interpretation. In order to assure information system's ability to evolve and adapt, it is clearly important first to acquire technologies that are capable of processing meanings instead of symbols and that are not restraining users in terms of data relations. In practical area of architecture, sysloop is an experimental technology aimed at overcoming limits of symbol processing and fixed structure paradigm, in order to establish adaptive and evolutive process agency for buildings, cities and larger environments. To overcome limits of symbol processing and fixed structure in the first place, and to do that in conditions of building process co-design (with industrial-grade parameters), several key technologies were needed to be developed from the scratch specifically for proposed system. The proposal is constantly developed namely on the first author's family house that serves as its prototype (see Figure 1) and operated in other environments such as office buildings, manufacturing, etc.

SYSLOOP: THE METHODOLOGY:

Figure 2: Entrance to the experimental building developed as the prototype of proposed system. (photo: Pánek, 2017)

The methodology is fully attached to constant reviews, prototyping and prototype's observation (see Figure 1 and Figure 2) and develops a "real life" Shön's concept of *'reflection in action'* (Schön 1983) in a physical built environment. The particular investigated prototype's co-design process is elaborated in a separate paper of this proceedings under the title: *'Spiralling Slope as a Real Life Co-Design Laboratory*' (Davidová, Pánek, & Pánková, in press). Due to the nature of the artificial intelligence and the nature of its development, the design methodology and the prototype itself merge into one. Therefore, the paper represents true *'research by design'* as discussed by Sevaldson and Morrison (Sevaldson 2010; Morrison and Sevaldson 2010) and because of that, the methodological section is fully integrated into the body text of this paper.
Sysloop is cross-layered and highly scalable concept and systemic design process of "allopoietic system", a system that is autonomous though dependent on the exchange across its environment (Dekkers 2015). Similar approach was suggested by Ghajargar, Wiberg and Stolterman for designing IoT (Maliheh Ghajargar, Mikael Wiberg, and Erik Stolterman 2018). However, sysloop design does not relate to things but living environment performance and is separate of internet. In this case, the exchange is performed through three types of co-design in several layers of scales: • co-designing of trans-disciplinary co-authors for machine learning, approaching the design process from different backgrounds; • co-designing of ambient environment of the prototype from whose observations and interactions it is learning, users included; • co-designing of artificial intelligence, big data and so called "universal human knowledge".

• co-designing of trans-disciplinary co-authors

Co-design, as we discuss it was explained by Sanders and Stappers in the means of co-creation as an active agency within the design process (Sanders and Stappers 2008).
Trans-disciplinary awareness of ability to automatically interpret human knowledge (as opposed to conventional data processing) allowed to design and implement concepts and use-cases which otherwise would be precluded by traditional processes, especially those in construction projects.

• co-designing of ambient environment of the prototype

Here the world environment is perceived as defined by Oxford Dictionary as physical and biological surroundings of an organism. The environment covers non-living (abiotic) factors such as temperature, soil, atmosphere and radiation, and also living (biotic) organisms such as plants, microorganisms and animals. (Oxford University Press 2004)
For example, due to presence of knowledge processing technology from early stage of project, it was possible to design a nonmaterial aspects such as environment dynamics, allowing designer to extend his/her concept and effectively preserve intended experience in course of time.

• co-designing of big data through artificial intelligence

For autonomous decision making, it is important not only to interact with users and local sensorial data but also with extrinsic knowledge, both static and dynamic. Such connectivity allows environment management coordination and optimisation across all scales, from single building unit through local community environment and services up to the city and global scale. Furthermore it constitutes preparedness for artificial intelligence assisted communication and content sharing.

SYSLOOP: THE TECHNOLOGY

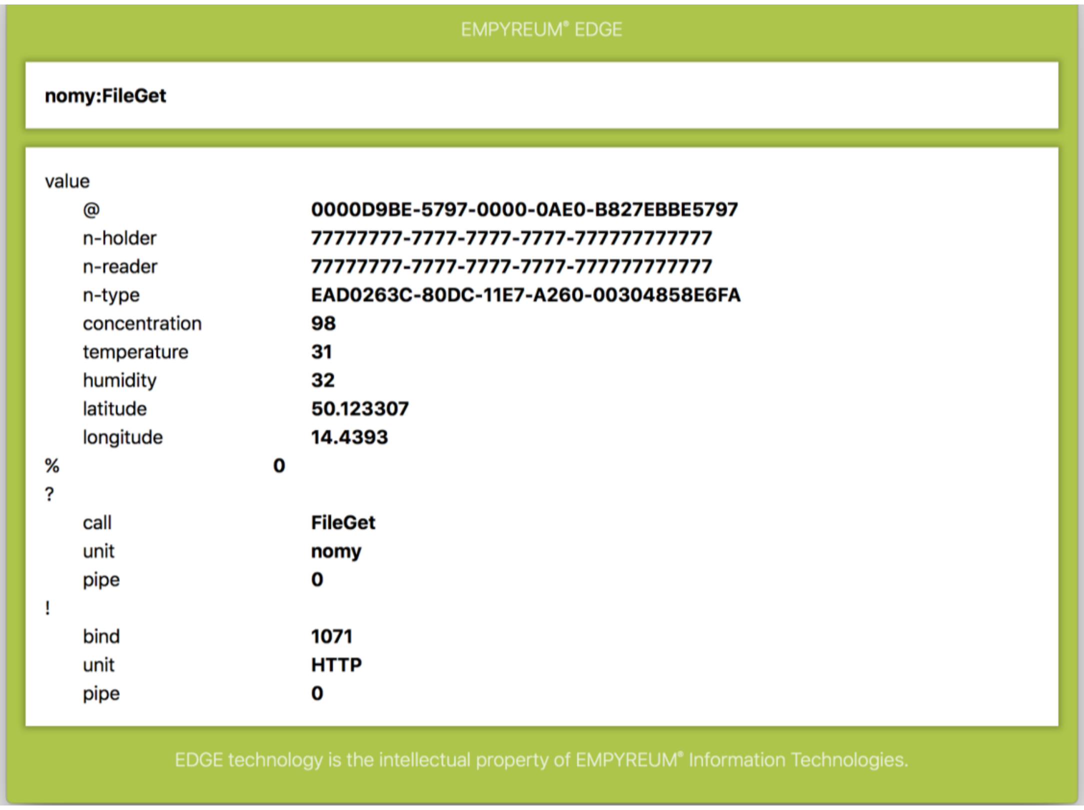

Figure 3: Trivial knowledge representation of radon concentration sensor within proposed system.

To eliminate restriction of fixed structure and fixed functionality, it is required to (1) dissociate data from methods of its processing systematically (“by design”) and to (2) comply with knowledge representation at all levels (data, methods, relations, communications) of the system. In order to do that, two key components needed to be developed from the scratch for proposed system, with these assumptions in mind:

- a knowledge integration platform,
- a knowledge base.

Once the system does not hinder oneself to work with structures as freely as with data itself, it is possible to handle information not only through symbols or patterns (as in relational model or statistical machine learning), but mainly through actual terms and actual relations, as in real life (see Figure 3). An adequate and practical way to do that is through natural language models. However, conventional (stand-alone) linguistic tools turned out to be insufficient until elaborated and amended through extensive trans-disciplinary effort. In order to exploit the potential of knowledge processing within real-time dynamics of the environment, it was therefore required to include two more key components:

- a knowledge data foundation,
- a natural language processing.

These four key components are described in detail in the following section.

The knowledge integration platform was developed with an ability to store and execute methods of data processing (i. e. transformations) as independent services across the network. Separate back-ends of these services and individual methods documentation are being generated and updated from source-code automatically by knowledge integration platform, allowing hassle-free integration, testing and agile development throughout environment life-cycle. As a part of the platform a "knowledge" communication protocol was developed with an ability to represent and transport high volumes of data of arbitrary structure in real-time.

The knowledge integration platform software is designed to be effectively operated at various scales, from embedded computer controllers to high performance servers. Typically, it is present across environment on larger number (i. e. hundreds) of single-board computers to interface with various hardware components, and on several local and / or remote servers for high performance computing such as real-time knowledge processing. At its every instance, the integration platform hosts one or more mutually independent software units, each implementing specific functionality. Through the knowledge protocol, these functionalities constitute assets that are available for loose coupling to perform real-time operations.

The knowledge base was developed with an ability to store and retrieve data with mutable structure. Within the knowledge base every aspect of reality being described (i. e. building component) has its own, arbitrary set of properties (mostly textual) that evolve over time. Information within the knowledge base is organised with respect to its logical relations, by means of an ability of property to represent relationship to another element (i. e. "has colour"). Due to natural language capabilities of the system, all information within the knowledge base are at the same time organised naturally, by means of a fact that certain elements shared certain subgroup of mutually comparable properties (i. e. "colour", etc.) described for each of them. Also, the internal storage allocation strategies and APIs of knowledge base technology are carefully designed with the assumption that some properties will potentially represent continuously growing time series of data from a large number of sources, such as sensors.

The knowledge data foundation was developed consisting of three segments:

- selected natural language models (English, Czech)
- fragments of universal human knowledge (i. e. basic physical units and equations)
- building environment model (i. e. sensors and actors interfaces and spatial coordinates)

Within the frame of knowledge base, way of describing human languages is identical to way of describing any other parts of reality – through terms and relations. As human languages stress perfectly natural relations between things, it is adequate and effective to employ these models in all processes of grappling all other data. With feasible extent of linguistic algorithms, it is then possible to make all knowledge available for automated interpretation within or outside the system.

Certain fragments of universal knowledge both static (data) and dynamic (algorithms) are required to be defined in order to support basic interpretation. For example an algorithm to calculate distance of two objects from their spatial coordinates, once defined, may be applied automatically on objects that have location, such as light sources, doors, etc. With universal and model-specific knowledge collected together, it is then possible to implement properly an ability of autonomous interpretation required to deal with specific real life environment tasks.

Utilising human language models, universal knowledge, building environment model and any other information in future are therefore all represented and accessible in the same way as actual terms and actual relations.

A natural language processing technology was developed with an ability to parse input and generate output in natural language, providing certain abilities of automated data interpretation within the frame of knowledge represented in proposed system's knowledge base. Through this technology, the environment is able to interpret and execute instructions and also answer questions formulated in human language.

All four key technologies described above are implemented in C programming language. Although the knowledge integration platform itself is designed to support any programming language, most of particular software components are also implemented in C. Proposed system also includes C language interpreter to support certain low-level hardware interactions effectively.

Aside from these key technologies, the proposed system also integrates few open-source solutions to incorporate functionalities, implementation and integration of which does not need adaptation in the sense of research subject of this paper, such as text-to-speech / speech-to-text (TTS / STT) transformation, transport layer security (TLS), and unix-based operating system (OS).

With the use of key technologies described above, all particular software components are operated on generic hardware nodes, which in turn may interface directly with specific equipment. Critical hardware nodes are interconnected using metallic cabling to maintain continuously reliable connection required for safe, real-time interaction. Where possible, these hardware nodes are connected in a star network topology in order to provide each hardware node with power supply option together with data through a single link (see Figure 4). When combined with managed switches or routers, single metallic link to each hardware node also provides significant benefits in terms of extrinsic monitoring, management and power efficiency. Wireless communication is also supported, but not recommended except for defensible situations due to variable signal strength and interference implications of buildings' environments.

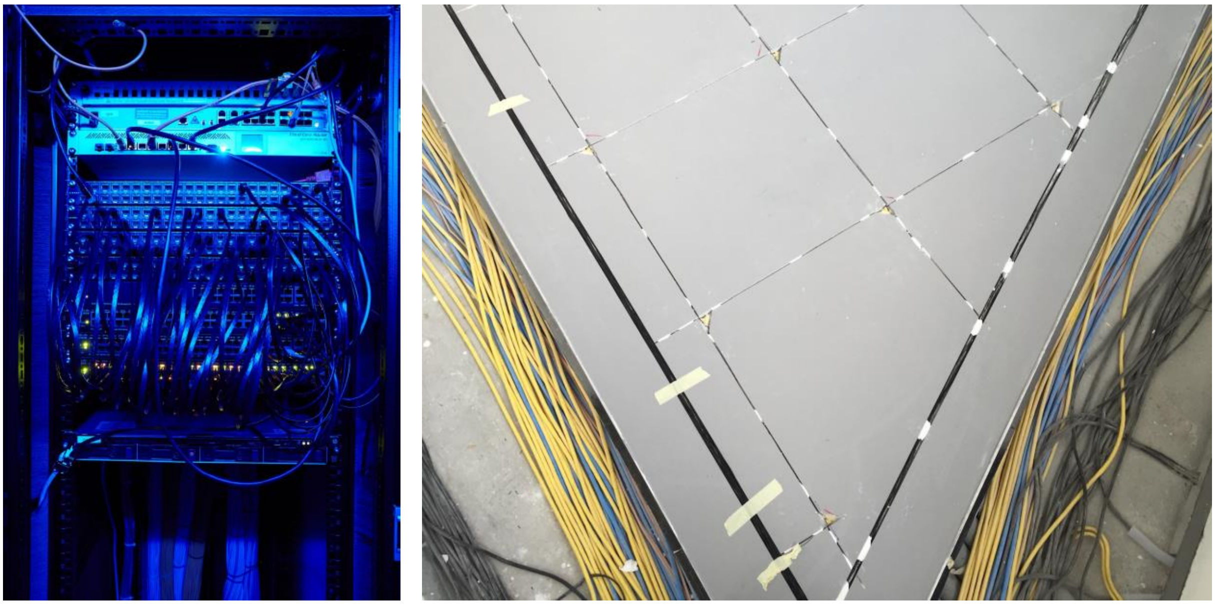

Figure 4: Wiring illustrations from prototype building, star network topology. (photo: Pánek, 2015)

Proposed system communication is performed through the use of IP (Internet Protocol), at transport (4), session (5) and presentation (6) layers of OSI (Open Systems Interconnection) model. For self-configuration, such us hardware node insertion or removal detection, and self-diagnostics it is using

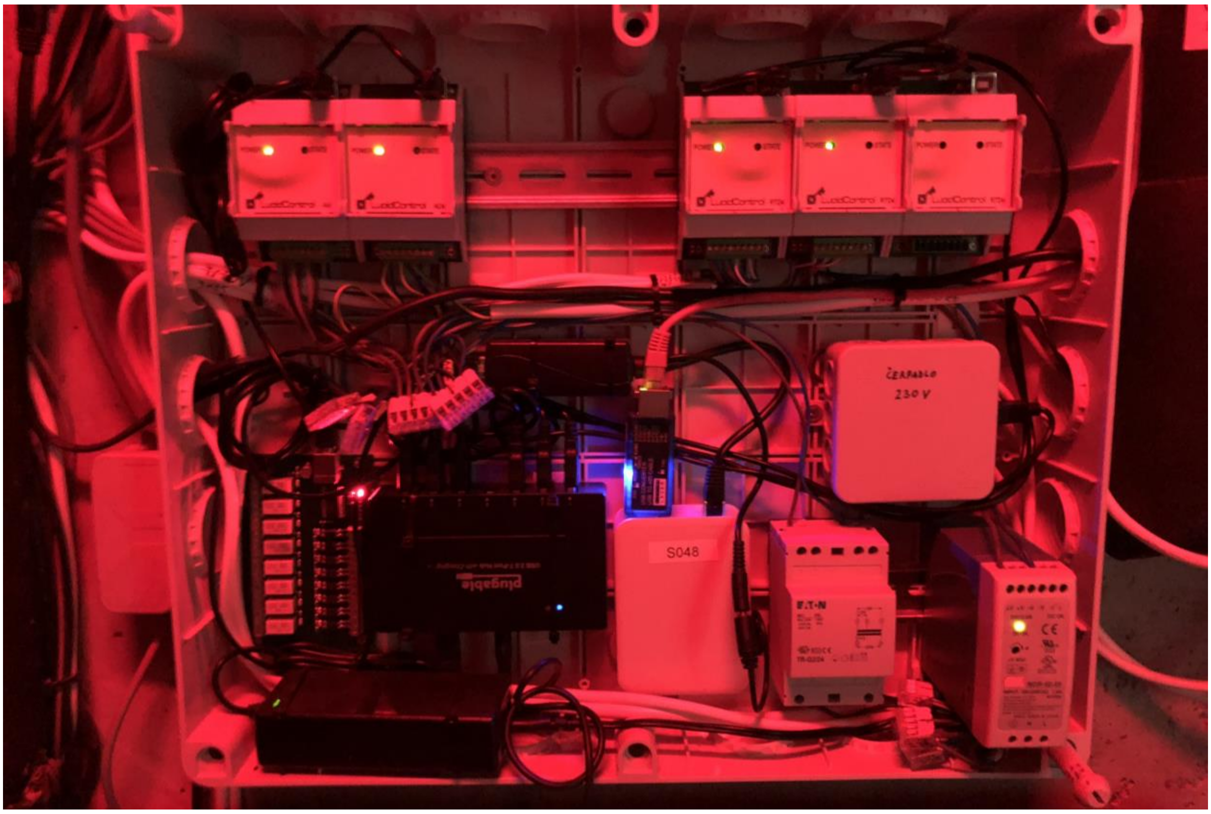

Figure 5: Prototype integration with HVAC compartment using direct I/O, Modbus and USB. (photo: Pánek, 2015)

Figure 6: Prototype integration with datacenter precision A/C compartment using Modbus. (photo: Pánek, 2017)

UDP/IP (User Datagram Protocol). For general communication it is using TCP/IP (Transmission Control Protocol) with altered fragmentation parameters in order to maintain control over latency.
Proposed system communications support both link (2) and network (3) layer switching. It is therefore possible to operate control-loop within local isolated network as well as control-loop distributed across separate sites interconnected by Internet, where required.
General intention of proposed system to transfer as much complexity as possible from hardware to software domain (in order to gain reliable real-time control) implies preference of single-purpose components over special-purpose appliances. Therefore an ability to interface directly and effectively with hardware components (i. e. individual sensors or controllers) is as significant as ability to absorb and control smart, usually stand-alone systems, such as air-conditioning technological compartments (see Figure 5 and 6). For example, within proposed system, it is not adequate to implement lighting control with higher-level protocols such as DALI (Digital Addressable Lighting Interface) where lower-level protocol such as DMX512 (Digital Multiplex) can be used because real-time dimming properties are hard-wired or throughput-limited in the DALI case, while complete control over dimming curve in real-time is available with DMX512. What can be considered less important aesthetic gain in case of decorative light, represents qualitatively different situation if dynamic digital signal processing is required functionally across certain building automation layer. As signal transformations are essential to many layers of designed environment, proposed system implements generalised software forms of digital signal processing (DSP) algorithms to perform tasks that are conventionally solved through dedicated electronic circuits, such as Arbitrary Waveform Generator (AWG) or Arbitrary Waveform Transformator (AWT).
Through generic (universally capable) hardware nodes, proposed system interfaces directly with individual sensors and actors over low-level bus standards such as GPIO (General-purpose input/output), UART (Universal asynchronous receiver-transmitter), I^2C (Inter-Integrated Circuit), or SPI (Serial Peripheral Interface). Industrial equipment with a higher degree of self-reliance is supported through own implementations of proprietary RS-232 based protocols and Modbus standard. Peripheral devices are supported through 3rd party implementations of USB (Universal Serial Bus) standard and Bluetooth wireless technology standard (see Figure 5 and Figure 6).

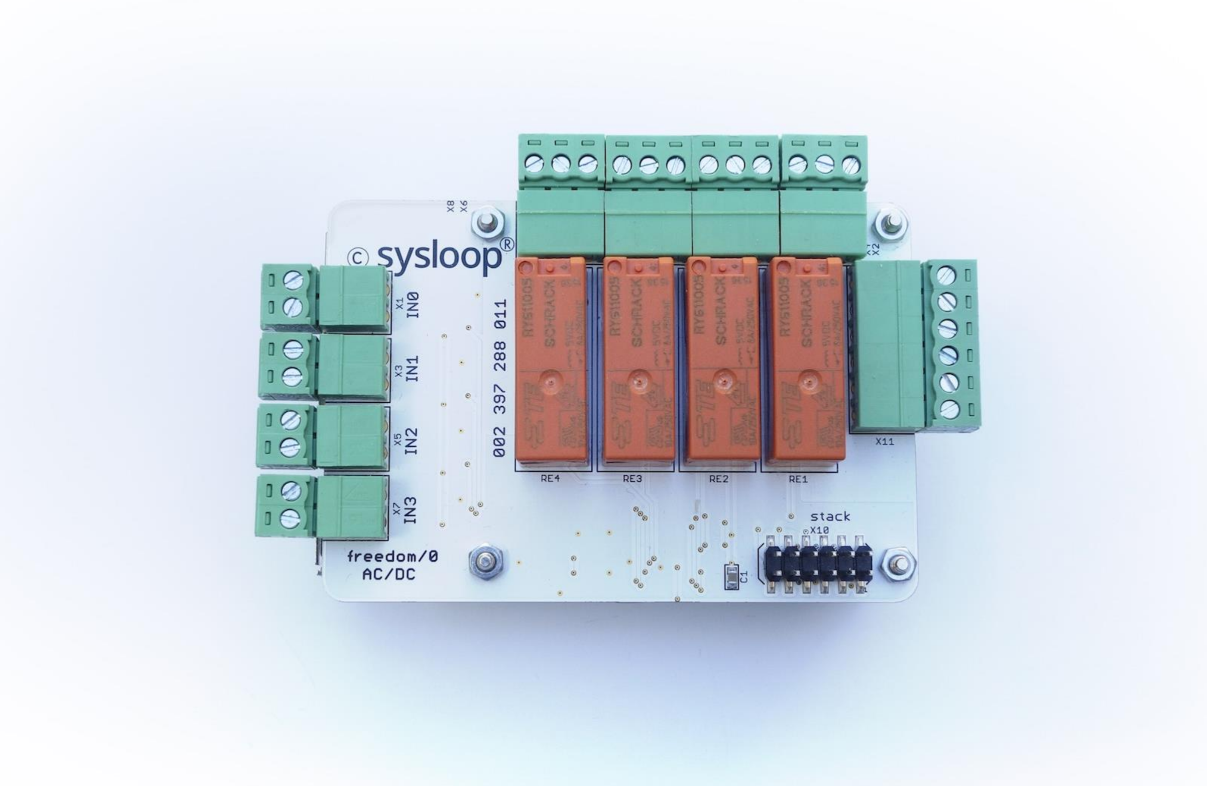

Figure 7: Example of I/O expander “freedom” developed for proposed system. (photo: Pánek, 2016)

In terms of low-level process control, proposed system forms a loose coupled system, performing combinations of feed-forward and feed-back interactions between elements. Real-time sensor / actor data, as well as high-level knowledge elements, are being streamed and processed through dynamically bound sets of functional units that are distributed across the environment on single-board computers and servers.

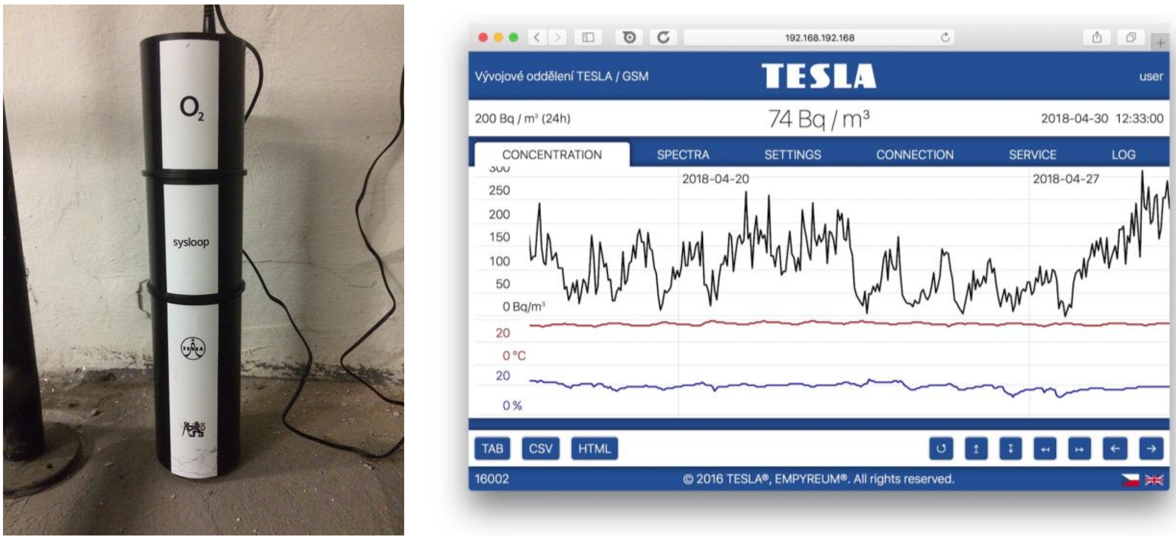

Figure 8: Real-time radon probe co-developed with creators of proposed system as example for integration. (photo: Pánek, 2016, graph: Pánek, 2016)

Figure 9: High-tech acoustic piano integrated with building artificial intelligence within proposed system prototype building. (photo: Pánek, 2018)

Several industrial-grade hardware modules were also developed for common interfacing with sensors and controllers, such as sysloop “freedom" I/O expander (see Figure 7) with hardware interrupt signalling to increase I/O management and power efficiency.

Various measuring instruments and sensors were developed and integrated within proposed system in order to demonstrate benefits and true potential of real-time knowledge-driven environment control.

For example, an integration of real-time radon probe (see Figure 8), loosely coupled with several active ventilation capabilities (as simple ventilators or advanced doors and windows opening systems, etc.), demonstrated practicability of health risk mitigation through informed real-time decision making, as opposed to conventional (cost ineffective) static construction solutions.

In another example, high-tech acoustic piano with electronic sensors for recording and electromechanical solenoids for player piano-style playback was integrated with the building environment through proposed system (see Figure 9). Deep integration at both MIDI (Musical Instrument Digital Interface) and DSP (Digital Signal Processing) levels allowed practical sound background interaction with other environment layers and with users, based on proposed system’s real-time knowledge evaluation.

Through same key technologies proposed system is intrinsically capable of acquisition, visualisation and interpretation of heterogeneous data in real-time. At city scale it brings technical pureness, uniformity and low complexity in terms of heterogeneous systems data collection and interchange (see Figure 10).

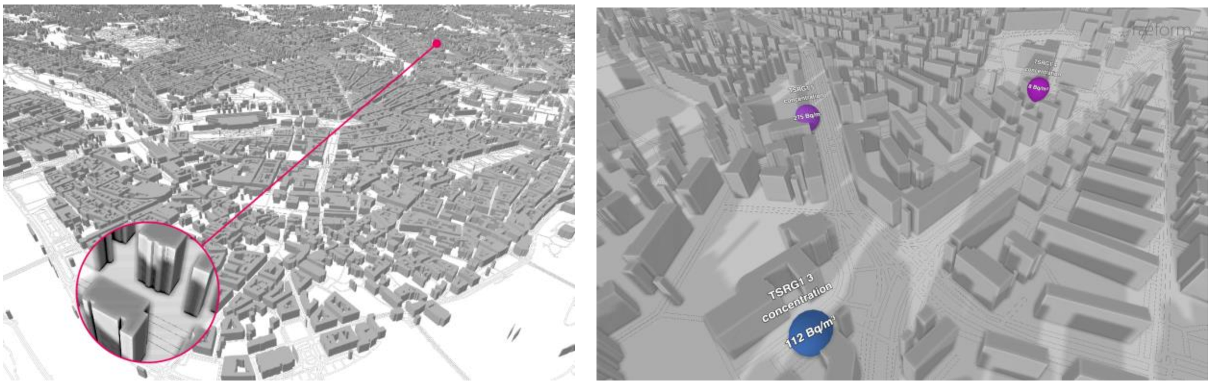

Figure 10: Element maps rendering within proposed system testing environment and its scalability. (illustrative diagram: Davidová 2018, generative model: Pánek 2017)

DISCUSSION AND CONCLUSIONS:

In relation to growing complexity, users are often concerned about operational demands and reliability and developers / manufacturers tend to focus on particulars at the expense of context. However, it seems, that the complexity will continue to grow and data cohesion of systems in general and artificial intelligence applications are required to cope with that complexity.

Requirement of paradigm shift from relational model towards knowledge approach is already apparent in the area of application software (where data is everything), as common information systems cease to satisfy everyday needs in always evolving complex reality. Since knowledge of not-uniform structure can be technically represented in a unified way, it can also be shared in a unified way. Technical accessibility of such knowledge from anywhere in real-time then represents not only quantitative, but predominantly qualitative advantage in terms of information systems and – in our case environment dynamics – continuity.

Similarly to the automotive industry, the complexity in building construction and automation can be and is step-wisely being transferred from hardware to software domain, in order to improve sophisticated capabilities without sacrificing operational simplicity or reliability.

Overcoming “critical mass” of integration leads to ultimate simplification from user point of view (and also at physical layers of technology), as such modern systems will contrive complex tasks like knowledge sharing, adaptation and self-repairing. Proposed system exploits the non-relational

approach to data processing to introduce such paradigm shift into the area of building design, construction, habitation and maintenance.
In the context of building design, construction, habitation and maintenance, proposed system copes with component granularity and overall complexity by exclusion of fixed coupling at both physical and virtual levels and introduces central artificial intelligence as primary process control agent.
Through a combination of knowledge processing technologies with loosely coupled architecture it was possible to implement advanced building environment capabilities, such as human instruction interpretation and question answering within the context of building.
Application of non-relational approach allowed achieving autonomous behaviour, alterable functionality and evolutiveness, qualities not typical for traditionally rigid areas of building construction and automation.
Proposed system allowed to integrate artificial intelligence elements into environment process control of a complex prototype building. Through same key technologies, larger sensorial network has been created in order to verify capacity of knowledge-oriented processing within a scale of a city. Such complex integrations not only create unique laboratories required for further trans-disciplinary research, but they also provide attractive way to demonstrate and understand importance of structural freedom, its attainability and feasibility even within fields where traditionally the opposite was the norm.
Through the fusion of processes-based co-designing co-performances of: • ambient eco-systemic agency; • large scale eco-systemic agency; • artificial intelligence agency into one performative eco-system, the sysloop prototype finds its place within the second author's newly design field *'Systemic Approach to Architectural Performance'* (Davidová 2017).

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