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Exo Case-Study and Prototype of the Dynamic Responsive Architectural System: The Key Attributes of Systemic Integration and Design – Part II

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Abstract As a part of the series of studies that have investigated different aspects of the *Exo* project and its arguments for the format and technical solution of the computed *architecture-instrument*, this paper focuses on main attributes and criteria that qualify this kind of architectural design for the categories of dynamic and kinetic responsive architectural systems, inquiring spatial and technological integration and design they claim. The concepts of these systems, theoretically presumed and practically tested in this project, have been contextualized within the wider field of research in this area (including relevant literature, comparative and referential examples), activating hereby interdisciplinary and cross-disciplinary potentials for resolving critical issues of the desired and analyzed architectural format. By converging sentience (remote and close-up sensing), electronic integration, algorithmic (software) command-and-control and automation, smart or intelligent performance, kinetics, performativity, adaptability, responsiveness, and interaction in relation to the variable (dynamic) input parameters, *Exo* claims the status of the representative example of the argued and investigated system design. Since the first stage of the experiment (the proof of a concept) has left the full application of targeted attributes partly unresolved, their detailed analysis and critical observation will be provided and presented so as to refine and more precisely direct further prototyping and project development. In parallel, the particularity of this case will be led towards the universal set of principles within the aim of its wider application in different design situations.

Keywords Dynamic and Kinetic Responsive Systems, Architectural Systems, Sentient and Algorithmic Performance, Programmable Architecture, Architectural Responsiveness, Kinetics and Interaction, Systems Design and Integration, Design Research Science and Methodology

*Continued from Part I: Vol. 10 No. 5

3.3. Autonomy - *Smartness* and/or *Intelligence*

Algorithmic control and object's performance could be specified through the property of *autonomy*, based on a degree of *smartness* and/or *intelligence* that algorithm entails. This attribute emerges from the specific type of an algorithm and its mode of operation – self-enhancement, decision-making and learning abilities that could be performed independently regarding the human supervision and involvement.

Autonomous installations express a certain degree of self-containment, even if based on a dynamic input media or some kind of interaction with the unpredictable sets of information. The experience of *machinic autonomy* (a*utonomous machine aesthetics*) is partly manifested by

the awareness of the inability to intervene in the machine's operating tasks and its performance (using herewith Broeckmann's notions on similar issues in machine art practices [35] (pp.107-108)). This would be one side of the interpretation or mediated experience of the algorithm's operation. The other deals with a degree of *intelligence* the machine can be assigned with – a particular designation based on the system's ability to learn and develop, or even perform creatively by autonomous decision making. A difference between *smartness* and *intelligence*, both depending on a type of an algorithm used for the machine's operation, comes to the fore while scrutinizing these issues. They both imply the system's expression of a certain amount of cognitive performance, but there is a significant difference. "*Smart* means programmed awareness of use, rather than *intelligence*" - it makes inert object aware: "... spaces are, through the application of sensors and software, being made aware of how they are being used (time, location) and, crucially, which or how people use them", while such awareness of usage and performance is stored (captured as logs) and transmittable for further utilization [31] (p. 99). While *smartness* provides the ways to track objects' performance based on programmed executive tasks, *intelligence* implies more complex and demanding logic within such performance and makes the object outsmart the initial settings with the help of the machine learning protocols; in extreme cases, *intelligence* might even imply the algorithm's capacity to develop itself further from the initial code. These last cases may be compared to the *seed AI* [36] (pp. 34-35) particularly important because of its ability to change its own architecture. While in the case of the *child machine* (Turing, 1950) in which the algorithm and the artificial entity start from some relatively fixed architecture [36] (pp. 27-28, 34-35) accumulating knowledge and information and thus learning from it, the *seed AI* "would be a more sophisticated artificial intelligence capable of improving its own architecture", ... it would be able to "engineer new algorithms and computational structures to bootstrap its cognitive performance" [36] (p.34) achieving constant "recursive self-improvement" [36] (p.35). The generic nature of such code usually implies the ability of the object not only to adapt its performance to registered parameters or behaviors and deal with the uncertainty, but also to anticipate and predict possible outcomes and situations based on learning and observation, or sensing. This could be enabled through either *sentient computing* or *tangible computing* [31] (pp.217-218), but in both cases it provides a higher degree of object's *autonomy* and unpredictability in interaction with humans and environment if compared to *smartness* A difference between systems that have a "narrow range of cognitive capability" and "those that have more applicable problem-solving capacity" [36] (p.19) sharpens the line between the notion of the *software in general* and the *intelligent* one. This is the main reason why one should be literate considering the software-tools he deploys, knowing exactly to what extent these devices could alter or support their initial design idea.

> *Posthuman theory conceives of intelligence, "thinking," and more generally the capacity to produce knowledge not as the exclusive, unique prerogative of humans, but as a distributed form of cognition that encompasses all living and self-organizing matter, as well as all kinds of technological networks. (Braidotti, note 19, [37] (p.11))*

The *autonomy* of the machines based on their self-generating principles (*autopoiesis*) implies that a set of relations among the machine components, required for constituting it or any other system as a unity, derives its properties from the ways that the living systems function. The identification of the machine with an organism which Maturana and Varela assign the notion of the *autopoietic machine* to (the machine capable of self-creation) [5] (pp. 140-141) is not a sheer metaphor or correlation as in some of the historical examples. It implies the use of biological or organic generative formulas (e.g., generative neural networks (GNNs) and genetic algorithms (GA) [34] (pp. 320-323)) for the machine's cognitive performance and self-enhancement. These algorithms are the main conditions for machine-learning abilities, enabling thus presumed machinic self-improvement, transformation, recreation, and eventually completely autonomous behavior and decision-making. Architectural system/machine that performs changes in this manner has already been proposed with the first ideas of cybernetic feedback interactivity and adaptability in spatial design (e.g. in the architecture of Cedric Price's *Fun Palace* devised in collaboration with Joan Littlewood, Gordon Pask, and John and Julia Frazer [27], Negroponte's *room-machine* [27] or its contemporary counterparts such as *Ada: the intelligent room project* [38] (pp.86-89)), as well as in more recent concepts of *smart* and *intelligent cities* and *environments* [39, 40, 31 (p.99, pp.217-218)], *code/spaces* and *coded spaces* [31], and different examples of direct applications of generative and evolutionary techniques in arts and architecture (e.g. [41]). The point of accomplishment of the highest degree of *autonomy* and machine (re)creativity, or the moment in which machines will be completely enabled to lead the life of their own, has already been designated or presumed in literature as the point of *technological singularity* or more precisely *intelligence explosion* [36] (pp.3-4). The *autonomy* in regard to certain cognitive operations is the main criteria of difference between *smartness* and *intelligence* – the first one a sheer programmed awareness of its use and performance, while the second, an ability of thinking, inferring, problem-solving, and decision-making based on learning algorithms and their capability to engineer their own structure, perform self-enhancement with information and experiences obtained in the course of this learning process. The latter, it has been assumed, will finally lead to the highest level and form of machine cognitive performance – *superintelligence* ("any intellect that greatly exceeds the cognitive performance of humans in virtually

all domains of interest" [36] (p.26)).

The abilities and designations of the architecturally incorporated, integrated, or engaged computer networks and algorithms, alongside the type of cybernetic control and its degree of openness, are thus central to the initial theoretical and technical positioning of the architectural concept and its correct definition. *Exo* used only basic coded algorithms for the first tests, but the whole scenario does presume the final *intelligent algorithmic integration and performance* in later stages (contained in and defined by proposed and constructed scientific and artistic research and prototyping methodologies).

2.3.1. The Synthesis of Sentient and Algorithmic Performance – Integrated Intelligence

Since the instrument rethinks the biological counterparts of its machinic design solution [1] (pp.25-26), and since sentience, data processing, and actuation have been expressed as highly discrete or systemically fragmented operations, the question of smooth continuous performance of a kind of *integrated intelligence* and the relation between biological and machine procedures, do appear as relevant topics for discussion. Having "presence as 'local intelligence'" ... "somewhere between the artificial and new kind of natural..." as Thrift and French would argue [31] (p.5), algorithms and protocols could be investigated against the criteria of biological and machine assets – their difference or convergence. Starting with their initial arguments that have presented software as "not [being] sentient and conscious while exhibiting characteristics of being alive" [31] (p.5), through different types of machine learning algorithms which make them closer to biological systems, (deep learning algorithms and neural networks [36] (p.6, pp.9-10) such as generative (adversarial) networks, convolutional networks, evolution-based algorithms (e.g. genetic algorithms), etc.), and finally complex multisensory integration and processing (with extremes in predictions of *superintelligence* [36] (p.26) and *technological singularity*), the technoscientific development might revoke initially posed claims that AI lags behind the human intelligence due to still insufficiently satisfying performances in certain aspects. This refers mostly to sentience and emotion, but they have also been significantly advanced in the last couple of decades (e.g., *Affective Computing* [34] (pp. 322-323)). A degree of biological emulation has reached the highest level of precision going towards the perfect technological substitution of biological counterparts (machine prosthetics), or further towards the production and engineering of new biological systems "spanning the core fields of biotechnology, nanotechnology, information technology and cognitive neuroscience" [37] (p.9). By adding sentient performance, those formerly impeded areas gained increased likelihood. A research and development (R&D) programs working on automated, *multi-INT*, problem-centric architecture (an effort to fuse multiple intelligence capabilities (*multi-INT*) into an end-to-end integrated system that will influence the automated collection and actionable response), revolutionize the current sequential tasking, collection, processing, exploitation, and dissemination cycle (*TCPED*) by enhancing it into a learning and adaptive cycle (Sentient R&D program [30]), all through use of sensing technologies. It may be said that such a prototype could be the ultimate model for the *Exo*'s and other object's performances that share the same objectives.

The software is also responsible for active interplay within the architectural settings. It animates static object-forms and systems and informs with a special kind of life a non-livable matter. Thus, it enables architects to conceptualize, design, and produce active dynamic forms. On that account, it represents convenient means and formula for realization of the next two pairs of design objectives and attributes – *kinetics* and *performativity* (3.4), and *interaction* and *responsiveness* (3.5).

3.4. Kinetics and Performativity

From the systemic point of view, the kinetic system is a system capable of performing its own (mechanical or sensory-mechanical) reconfiguration, whereas the kinetic change and transformation could depend on both *soft* and/or *hard* control mechanisms, actuation, and structural transformation. Furthermore, the *intelligent kinetic systems* which are based on algorithmic control and sensory features, and mostly applied in the current *artificial architectural kinetic systems*, can be explained to "emerge by isomorphic convergence of three key elements: structural engineering, sensory technologies and adaptable architecture" [20] (p.99). Based on application of the software control and integration, and embeddedness of intelligent systems within the kinetic ones, they also imply new relations of contingency between the attributes of *autonomy* and the attributes of *kinetic performativity*.

The very term *kinetic architecture* has been coined by William Zuk and Roger Clark and officially authorized in their book of the same title in 1970 [42]. It has been defined as a "transformable architecture capable of changing its physical geometry" thus capable to enact its physical reconfiguration, as Zuk and Clark have approached this problem [17] (p.750), but also as the "built objects or their components of variable locations or mobility and/or variable geometry and movement" [20] (p.91). This kind of architecture has undoubtedly been receiving the increasing attention more recently, but there are, however, apparent and important predecessors to its machine category [1, 2, 5]. Still, a difference that distances this concept from its historical origins and varieties rests not only on the large time-span between them and their technological incomparability, but also on the very design processes, design logic, and overall philosophical paradigms proceeding from their accounts or informing them in the first place. A transition from the mechanical to the information age, for instance, has brought *interactive*

machines to architecture [5] (p.119) alongside the whole field becoming the new "kind of 'cultural mindset'" as Shanken explains [5] (p.120). Different mechanical or kinetic solutions in architecture, or solutions with certain logic of the architectural systems being mechanical and kinetic in character, have been dramatically changed with the advent of cybernetics, algorithmic control and automation, sentient and electronic technologies. Most of today's architectural kinetic solutions are computer/code-based (software systems support and control their mechanical movements), while robotics became the most important adjacent field of research and practice required for enhanced architectural tasks and performances these solutions exhibit.

The kinetic architecture presumes some kind of a kinetic objective, problem, and performance as influential and constitutive for the programmatic and formal architectural concept and solution. It incorporates movement and mechanical performance into the very design process. This is a specific condition that differs from some kind of reflection of external dynamics in the mostly inanimate matter (mere acknowledgment of the time component or formally "frozen" and solidified dynamic forces), even though this approach does share some instances with formal *sculpting* of structural dynamics. Here, the movement is literally present and this happens through some kind of a change of spatial formation, engaging an "engine" (force) in order to carry out designed kinetic performance. In the light of some recent investigations and experiments in the field, the movement can be interpreted in two ways. The first one relies on the traditional logic of mechanically driven components, while the second one focuses on certain intensive attributes or factors [43, 44], either external or internal to transforming matter, inducing the object's formation (or *becoming*) and inherently determining its design. The latter has origins in ways through which the organic processes unfold in nature and has been developed in recently proposed *soft* approaches to matter's kinetics [45, 5, 12] or "'soft' form-changing material systems" [45] (p. 334). Through their use, architects are trying to replace or minimize "intricate and high-tech mechanistic joints, actuators and control" or "'hard' mechanical components" [45] (p. 334, 335). Starting with such an objective, this line of architectural design research goes even further down the dimension scale towards the solutions based on atomic and molecular kinetics of substances and materials (the *matter*) that are used for architectural design. In such cases, the formal transformation of the material or some architectural component (and consequently the whole structure or an object) has been environmentally and internally chemically, thermally, magnetically, or electrically triggered, while this first-order movement becomes an actuator for another kinetic expression in the chain of kinetic events and reactions on different scales of expression (such as in hygroscopic experiments conducted by Achim Menges [46] (pp.122-123), Matthew Hume (Warped, 2008) and Omar Khan [47] (pp. 50-59), or as demonstrated in *Radiant Soil* and *Hylozoic Grounds* installations by Philip Beesley and various collaborators [48, 49, 50(pp.121-141), 51(pp.78-89), 52, 46 (pp.102-103). These examples follow biological and chemical instead of (or in addition to) the mechanical principles. The logic they employ differs significantly from the transformation that needs some kind of external power (e.g. the electric power supply) or actuation components (motors) to be set into motion. Instead of the system of mechanical connections, "the material becomes both sensing and actuating system" [47] (p.55). The latest experiments use both assets, while many ground their research objectives predominantly on the premises of the concept of the *informed matter* (constructed in reference to the information sciences, information paradigm, and digital technologies application in different disciplines (e.g. chemistry [53, 54 (pp.199-201), 55(p. 3)], or architecture and architectural materials [56, 57]) and *intelligent* or *programmable matter* [19, 58, DARPA in 59, 60, 61 (p.153), 62 (pp.15-36); also in 1 (p.31)] focused on digital programming and control of the *processes of organization and formation of matter* or initiation of its autonomous formation (*autopoiesis*). The latter is a direct investigation into the ways of embedding *intelligence* into the processes of *matter formation*, as well as a systemic networking of algorithmic integration and machine learning with material responsiveness.

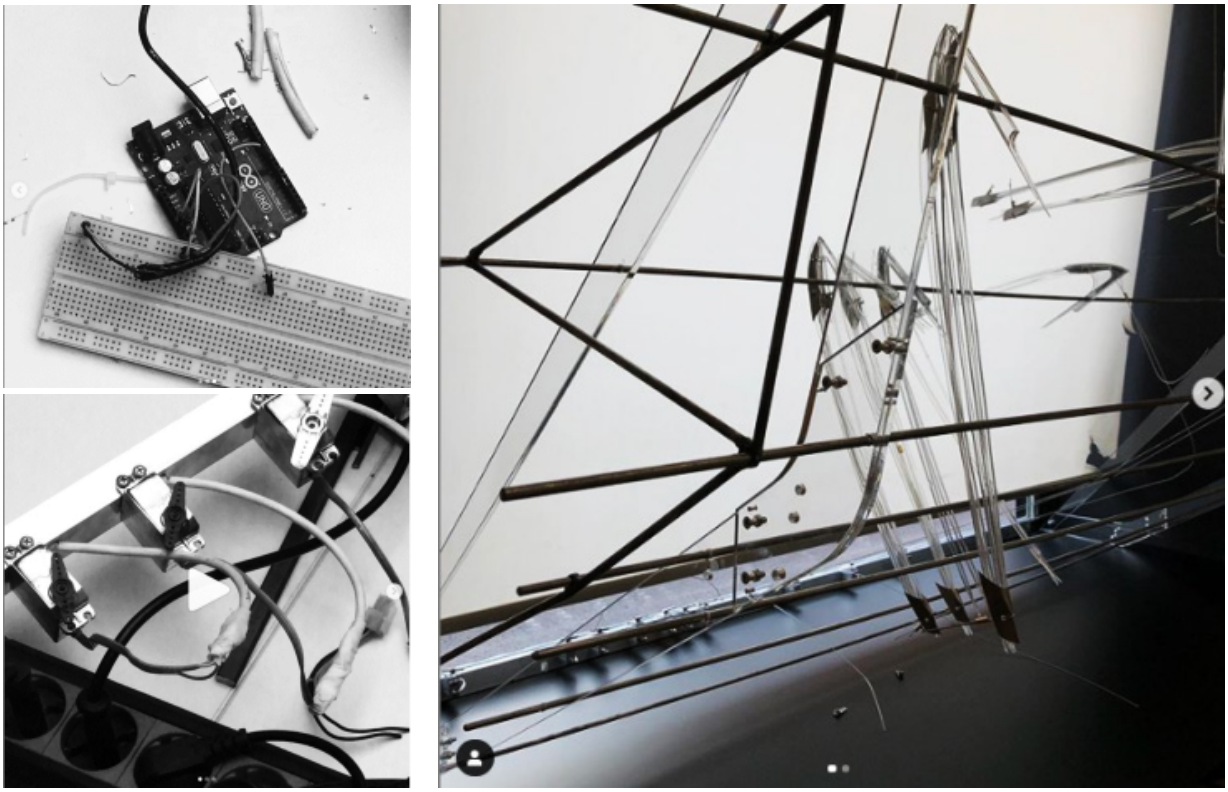

Figure 4. The site-specific assembly of *Exo* components. **(a)** Electro-mechanical, and digital integration - Arduino microcontroller and servo motors. **(b)** Bearing construction and kinetic components (*feathers*), the window of the *Kolektiv Gallery*; Author: Dragana Ćirić ©; Software integration, electronic and technical support: Aleksandar Popović (*Karkatag Kolektiv*); Photography: Nikola Abramović © (https://kolektiv.rs/3m3/exo-global-eyes/)

Figure 5. Exo [global eye(s)] – Kinetic elements and their performance, *Kolektiv Gallery*, 16-28 October 2019, Author: Dragana Ćirić ©; Photography: Alex Murray ©; Video: https://vimeo.com/368229565

In addition to somewhat wider investigation of this field in previous paragraphs, *Exo* uses information-triggered mechanical (motor-based) actuation controlled by the algorithmic protocols and human supervision (scientific objectives and performance scenario). The starting parameters for kinetic mechanization are either "sensed" and extracted from the environment (*mode 1*) or obtained from online databases (*mode 2*) and by the tracking software (*mode 3*), further subjected to conversion into deployable form of input information. Ten servo motors, activated and governed by the Arduino microcontroller system (which contains power inputs and outputs, can read sensors and information from different software and internet sources, convert operative data into the kinetic instruction and thus operate the system through simple decisions) (Fig. 4), initiate the movement of the kinetic

components (*feathers*, Fig. 5) through architectural geometry, structure, and mechanism of connecting cables (the system of connections). It may be said that *Exo*'s kinetic performance is mechanically, architecturally, electronically, and algorithmically controlled and designed.

The second attribute that appears among major descriptive criteria, which is in this particular case specifically related to *kinetics* within one of its spatial operational modes, is *performativity*. *Performativity* arises from the question of *what something does* in comparison to the question *what it is* or *what it says* (in architectural terms, it questions the move from "what building is to what it does" [63] (p.7), or "in what ways does the building act" [63] (p.8)). It clearly embeds the *change* expressed in different effects, which depend on the architecture's degree of *interactivity,* and its ability to employ and display action. It is the expression of architecture's operational aspects that also create distinctive aesthetics and demand application of certain technologies (even though temporary suspension of the aesthetic aspects might be argued when orienting investigation itself centrally towards the issues of operationality [63] (p.7)). The feature of *being performative in relation to space*, or any other entity, brings in the "processuality and immateriality … by emphasizing the act or action, relation, movement, perception" [64] (pp.6-7). One can distinguish two basic perspectives: (1) *the performativity within the architectural object* ("as the quality of form, space and program/action/act/behavior" - "dynamics or variables that architecture entails and assesses in the course of the design process …," [64] (p.9) and (2) *performativity of an architectural object* (effects, conditions, and contingencies that become inscribed into the architecture later in the course of its use [64] (p.9), but whose successful embedding has actually been secured through already applied design method, present or premeditated in its spatial logic). Thus, there is a difference which plays an important role in defining and describing the *mode of performativity* present in spatial concepts, between:

(1) *performance in architecture* (the acts and programs architecture houses and enables),
(2) *architectural performance* or *performance of architecture* (performative aspects of architectural constitutive elements and the system as a whole – e.g. kinetic transformation, digital and light effects, durability and behavior related to the relevant environmental and structural parameters, etc.) and
(3) *performative architecture* ("interactive architecture of various degree and character of transformability of spatial disposition with the induced reaction emerging from the posited and performed information and sensations" [64] (p.1), which also literally and actively *performs* (or acts out, emphasis added) within a certain spatial situation, conceived as a stage [65, 66 (p.205)].

Kolarevic summarizes the notion and dominance of the questions of *performative* in architecture relating them to the late 1950s paradigm and narrative shifts in other sciences (linguistics and cultural anthropology in particular, but also in technologies and other research areas [66 (p.205)), and confirming construction of "the *meta-narrative* with universal aims that are dependent on particular performance-related aspects …" [66] (p.212). These aspects counteract the "fixity of form, structure, value and meaning" through argument of the "dynamic network of intertwined, multilayered processes" that, attributed with the concepts of *fluidity* and *mediation*, shape and influence all the entities and matter temporally [66] (p.205). In architectural terms, performance-based aspects can be present on different levels, while within the theoretical framework, the performative architecture grounds itself on "performativity as a paradigm" – as a specific architecture that possesses the capacity to respond to change [66] (pp.205-213).

> *In performative architecture, the emphasis shifts from building's appearances to processes of formation grounded in imagined performances, indeterminate patterns and dynamics of use, and poetics of spatial and temporal change. The role of architects and engineers is less to predict, pre-program or represent the building's performances than it is to instigate, embed, diversify and multiply their effects in material and in time. [66] (p. 212)*

As can be seen from numerous standpoints and interpretations of reappearance and realization of the *performance paradigm* at the beginning of the 21st century [65], *performativity* in architecture primarily has to do with uncertainty, unpredictability, and planning for perpetual change and motion. It includes and premeditates certain occurrences in design concepts, thus *spatial flexibility* and *adaptability*, or a certain degree of openness for unknown situations and events in the long term. This dynamic attribute could be materialized differently:

(1) In relation to external conditions, presenting their operationalization in order to design and embed change and transformation as a specific ambiental quality and quality that works in line with environmental dynamics;
(2) As a sufficient architectural and structural resistance to these external and, additionally, internal forces and interactions (*dynamics*) and their possibly hostile effects (mostly investigated within the field of structural or construction engineering, which deals with questions of "connection between the formal architectural idea and the rules of the stress flow" [67] (p.141), but also found in *performance-based approach* [68 (pp.115-121), 69 (pp.123-133), 67 (p.141) that puts emphasis on "beauty of force-driven formal articulation" [66] (p. 210)).
(3) Within the programmatic register, implying shifts in function and principles of certain typologies, or "building for events that are unforeseen, with an

unpredictable or at least variable use of space" [70] (p.163).

(4) In formal architectural properties [67, 70] implying the emergence of new concepts such as *generative systems of formal production* and *finding of form* [71] (p.195), *performative morphogenesis* [72], and *incremental spatial growth* (e.g. *field conditions* [73, 74 (pp. 122-124)], or Metabolist spatial expansion and growth [32] (p.31)), alongside today's more literal formal transformations based on *robotic architecture*, *structural shape control*, *variation* and *versioning methodologies*.

The presented analysis reveals different levels (usually inseparable in a design process) at which all these dynamics appear, are expressed and converted into the architectural terms. The change and architecture's adaptability, in line with the performative requirements, could be expressed:

(1) *in time* (defined under the time-driven conceptualization techniques "which also include socio-economic and cultural forces within the larger context" [71] (p.195)),

(2) *in space* (regarding spatial occupancy and capacities – with literal motion, kinetics, and restructuring),

(3) *in the material* or *matter* (in the processes related to the *programmable*, *computed* and *informed matter*, or in the *analogue computing of form*), or

(4) all of them at the same time and in combinations, incorporating the input parameters and expressing the output effects on different levels (climatic and environmental, cultural, intellectual, aesthetic, spatial, programmatic, etc.).

Format of the open system, which allows feedback and interactivity (thus constant self-improvement and self-reconfiguration), multiple alternatives, scenarios, and possibilities, represents the ultimate (generative) mode of a desired architectural performative state. This, however, could be easily applied only at certain levels, in certain architectural elements and systems, in parts of the design process, or in specific contexts (more easily in virtual (by simulation) than actual and real). Still, the *adaptability* needs to be valid at the level of architecture as an integrative whole, and this can be accomplished by avoiding a complete split between the building as a system and its components (e.g. envelope, [75] (p.152)) as well as by the transfer of *performative character* from the specific aspect or a building part to the architecture as a system and an assembly. Even though some cases at times do resort to different kinds of autonomies of singular architectural elements and aspects, eventually they specify and influence the whole of systemic properties through their synthesis.

The concepts of change and variation in architecture come from the design endorsement of *dynamic paradigm* and *responsive dynamism*. In the 1990s, these long present ideas [11] have been finally digitally formalized and made part of the particular line in architectural design thinking and practice (at the time advocated and investigated by Greg Lynn Form, UNStudio, OMA, etc., [76] (p.169)), thus also becoming professionalized and fully applied through new design strategies. Here, the *performativity* has emerged from tactics of operationalization of such dynamics, or *flows*, irrespective of their sphere of origin (natural – topographic, morphological, climatic, etc.; economic and financial (related to *fluid market forces*); cultural; intellectual; political; or other). These *flows* were used as "generative components in otherwise conventional design relationships" [77] (p.60), and the newly posited concept of *active morphing* investigated through formal variations. Therefore, the spatial or architectural capacity to respond to or embed dynamics, and to express active and interactive behavior, have been digitally achieved.

Besides these interpretations, the *performative property* also refers to "acting out" or a capacity to entail and mediate the space as an *event*, implying, above all, the difference embedded in its appearance and each reappearance, or reenactment over time. The *event* is a time-based concept that implies the unique experience and unrepeatability, which makes the environment of its enactment unfinished regarding programmatic and behavioral content. In that respect, *performativity* can be introduced to the discussion as referring to the effects that architecture generates in different registers (cultural, economic, environmental, etc.), producing significant changes within its milieu and living spheres alike. In such mechanism, the changes that the architecture activates become the new input information, and this kind of a feedback-loop solidifies as the basic condition of *performativity*. In other words, it has been claimed that "the material, organization and cultural change that occurs as a result of this perpetual feedback and two-way transfer of information is *performativity*" [78] (p.179). Such a statement, perhaps, partly resonates with McKenzie's perspective. His notion of a kind of *general theory of performance* [79] (pp.3-26) [5] identifies similar organizational, cultural, and technological aspects regarding the convergence of presumed *performance paradigm*, *performance stratum,* and *knowledge forms of statements and practices* (*performatives* and *performances*). While clearly delimiting his focus (organizational, cultural, and technological interpretations and areas of the *general theory of performativity*), McKenzie just plainly mentions interpretations in other disciplines (e.g. philosophy, health sciences, and finances), and one can be directed to pose the same question of the *general theory of performance* in relation to architectural discourse, as well. Within this attempt, by mobilizing McKenzie's perspective, the question of *performative as knowledge and power* also comes to the fore[6]. Architecture

5 McKenzie's view on *performative* moves between the efficiency and standardized predictable enactment on the one end and creative and critical, unpredictable, and nonstandard performance on the other end of the scale.

6 The questions to be asked in this respect are: If architecture is a form of authoritative speech, a discourse and a statement, in what ways does it bind the 'power' within? What kind of knowledge is performed and

could be analyzed as a discourse, speech, or a text, a self-critical and self-reflexive theoretical testing of its own grounds, producing various effects within and outside of its own discipline. Thus, *performance/performative* can be present at the level of writing, production and communication of architectural knowledge, or their power expressed and embodied in architectural acts and practices. This framework, however, will not have a more significant role in this particular analysis, being just acknowledged as one of the possible thinking registers.

Another term important for the analysis of the concept of *performativity* appears in architectural literature. The *performance design* has been explained as "a set of practices that had emerged from general systems theory, operations research and cybernetics, at the end of World War II" [77] (p.57). It relies on the work of practitioners designated as "system analysts, system engineers, operations researchers" whose approach has been based on a scientific method of analyzing predominantly functional requirements, but including psychological and aesthetic ones as well [77] (p.57). In this concept, the traditions of functionalism do reappear, but their mechanical and organic analogies to *performativity* give way to more scientifically robust and powerful concept of *complex adaptive systems* [77] (p.57), and new scientific explanations and discoveries of the *new age*. The *performance design* takes another line of development, departing from its technological and technical origin in modernism, and leaving it, as it can be seen now, as just one of the modes to which the attribute of "being performative" can refer when related to architectural thinking, design process and practice.

Performance also implies the "active" mode of the investigated subject. This is usually opposed to passive analysis and reception that only accept information but do not respond or engage with it, nor do they operationalize it within some kind of a self-improving and self-learning framework. *Performative simulations and analyses* are particularly deployed in a design process. Design process undoubtedly possesses a higher degree of flexibility and the capacity to investigate and represent multiple scenarios and variations. This is most firmly evident if one compares the process to the final built state which has to accept a relatively reduced mode of principal *performativity*, at least in certain aspects. At the level of a design process, however, a reconstitution and reconfiguration of an object, system or environment unfold as consequences of the "self-reflexive discourse … of the designer's thinking process" [71] (p.200), which converges formative parameters (criteria), *performance-based variations,* along with subjective or shared qualitative decision-making within the dynamic, generative conceptual architectural design explorations. Recent architectural theory and practice which use *performance as the guiding factor in design* [72] (p.4) or the *model that couples principles of performance with principles of generation* [72] (p.5), have made a significant move from simulations (manipulations and variations of the digital model) to *real performative behavior* which manages to embody such dynamics in the concrete space. *Exo* puts special emphasis on this applicative side and real spatial experience of kinetic performance – the reconfiguration of form, structure, and program altogether, not only in cognitive and virtual but the real space, as well.

From the performative perspective, architecture can also be observed as a *medium*. The status of a *medium* implies that the objects are valued not by their content but by action and experience they induce due to their form of communication. The notion that moved connotations of the *message* from the *content* to the *means of transfer*, contained in the statement "… it is what they do that gives the key to their functioning" [80] (p.16) goes in line with the main claim of *performativity* cited earlier by the statement that 'it is not important what something *is* but what it *does'*. These two premises converge at the point that implies relation between performative assets and communicative format. Concepts and ideas can be posited into the world by means of different communication forms, spatial mediums being some of them. These mediums, like architecture, will allow, demand, and generate different protocols and possibilities for the engagement. They will enable one, for instance, to literally "enter" and enact advocated concepts while engaging with them and with space in a bodily manner. In addition to engaging with thus activated thinking processes and spatial cognition (premeditated and gained through action), they will also enable one to "read" architecture as a text. The book as a medium, on the other hand, will engage predominantly one's thoughts and imagination, placing performative possibilities in successive and time divided moments by which the text and reading have been organized and structured, while it will express the complete inability of any kind of active participation of the reader regarding its content, other than cognitive and *post antes* behavioral. As a *medium*, the architecture becomes measured by the *medium*'s evaluation criteria - its *possibility of interaction*, a *degree of active multiple participation and interpretation* (clarity, directness and rigidness on the one side, and openness and ambiguity on the other), which all go down to the lower or higher *possibilities of performative operation* and the *set of expected and unexpected responses*. This perspective and McLuhan's explanation assign to architecture the popular *hot* or *cool* designation [80], whereas a higher degree of *performativity* is related to the latter (the *cool*) by embedding strategies and tactics that prevent the content's stability and perpetuate the *constant process of becoming*, refinement or change that unfold in real-time (such as the one we find in learning algorithms and cognitive processes). *Architecture as a medium* employs the potential and the capacity of communication, even *conversation* (first found in the concept of "architecture as *conversing* and *teaching machines*" of

mediated through its execution and does it represent or generate a specific line of thought, knowledge and skills?

Price, Littlewood and Pask, and in the *conversational theory* of Nicolas Negroponte incorporating machine learning and intelligence [27]). It puts emphasis on communicational aspects and technological enhancement of architecture, in this regard as principal sources and frameworks of performative attributes.

As it has been elaborated, *performativity* in architecture has several interpretations, or appears at different levels: (1) in architectural conceptualizations and specific lines of thought, (2) in a design process, (3) in virtual or digital modes of architecture, and (4) in real architectural spaces, objects, and their components, that can *play* or *act out* concrete performative features, communicating thereby through their spatial medium. Applying the attribute of performativity at this last level, by attempting to materialize and demonstrate performative operations in concrete space and interact with users and environment, *Exo* argues experimentation that enables architects to learn about performative systems through their design and construction, to acquire system design skills, and more easily deploy all the related concepts in their future practice.

While the *performance* attribute and *performative philosophical, theoretical, and research position in architecture* have substantially changed and enhanced spatial thinking and practical solutions, the question of how performative criteria create beauty, act within the realm of aesthetics or demand specific technological and technical excellence to this end (as it has been demonstrated by Whalley [81] (pp.21-40, 38), and as opposed to more analytical suggestion for their temporary suspension by Leatherbarrow [63] (p.5)) remains an important question to close this section. The side of design related to humanities-based disciplines and their value of poetics [50] (p.135) should not be neglected, but finely posited and justified when specifically aimed at, particularly regarding its artistic and spatial immersive capacities. *Exo* relies on both scientific and artistic registers deriving and developing its aesthetic performative code and language from the scientific objectives and operations, and carefully shapes both, their disciplined (divided) and undisciplined (convergent) messages and actions within the environment.

The mode of *kinetic performativity* demonstrated in the *Exo*-experiment (where the expression of input dynamics and variables has been mediated by combining *mechanical*, *sensing,* and *information performativities*) enters another circle of refinement with the next set of attributes. The question of possible modes of adaptation and reactivity considering the parameters from the environment (natural, artificial, or synthetic), prompts *responsiveness* and *interactivity* as the next pair of derivative properties that could be embedded in the object's structure and geometry, form, behavior, and function.

3.5. Adaptability - Responsiveness and Interactivity

The term *responsiveness* and its interpretation in architecture have their origins in examples from nature and the theory of *complex adaptive systems*. As per this view, architecture is seen as an integrative part of the environment, open for and susceptible to changes of its properties, while being capable to operationalize these parameters in both dynamic manner (perpetually in time) and critical manner (controlling a degree and a kind of a given reaction in relation to them). Such architecture produces, emanates, or projects responses as a result of interaction (with environment and other systems within). In a more general sense, it represents a system *that according to the received data can react and adapt through its own sensitivity* [82] (p.245). Based on information exchange in a dynamic feedback between external triggers (or environmental drivers) and model's responses, the observed architectural and environmental entities are defined as *informed responsive systems* [82] (p.244). A discoursive framework, which shapes the interpretation of their logic, structure, systemic integration and performance summarized in this concept is *information paradigm*-based and supported by the fact that the property of *responsiveness* in artificial systems has been enabled by the electronic information network and its mediation between environment in general and architecture (as a designed micro-environmental model, also termed *responsive environment* [29 (p.132), 11 (p.13), 82 (p.245), 83 (p.182)). The response will be embodied in altered physical condition and expression of architecture, or in the information processing (data emission, mediation, and programmatic changes) at more abstract level of the architectural system's reaction and behavior – namely in different types of *performative alterations*. Thus, the attribute of *responsiveness* is usually parallel to, responsible or conditional for the *performative operations*, while both *responsiveness* and *performativity*, including *interactivity* which refines the domain of *responsiveness* (representing its subset [84] (p.205)), are mostly led to convergent outcomes.

Everything that is detectable by its frequency (or wavelength), be it natural or artificial, and enters the *Exo*'s range, becomes possible input data for the instrument's processing and transposition into the kinetic response. Whether belonging to the broadest scope of all detectable objects or narrowed down to the smaller group of those selected, according to the scientific and artistic objectives, it enters the analysis, expresses its influence and relevance through filtering, and becomes subjected to conversion processes. Performative effects and final disseminated information depend on the executive protocols and their capability of solving sensing and data-acquisition problems (such as those of the shadowing, fading, interferences, and noise uncertainty related to the "sensed" data), followed by operationalization of the selected information and control of the passive and active kinetic forms of *responsiveness*. Even though presumed *interactivity* and *adaptiveness* to external conditions and data (e.g., presence and activity of certain artificial objects) might not be immediately discernible, they claim the

position of the main instrument's objectives. When there is a direct insight into the synchronization and dependence between the input information (the activity of the tracked objects) and the output information (movement of the instrument's kinetic components and the active signal response), the existence of interactive play can be easily proved and identified. But this is not always the case. A staged performance might only appear *interactive* while actually simulating such condition, no matter if conducted as an intentional decisive act or for the testing reasons. In the *prototype-based simulation* or *Wizard of Oz experiment* "some part of a prototype is realized by something else than the piece of technology that should achieve that function" in order to deliver a "proof of a concept" [76] (p.174)). And while such approach is completely justified in certain cases, the possible unclear image of the motives behind it in other cases, is precisely the reason why the invisible contingencies mediated through algorithms have to be exposed, why the project's explanation and design should contain their specification, and why it becomes important to deliver evidence for presented claims. Such assertion has to do with the difficulty of the work's assessment and the need for an insight into the fulfillment of the artist's, researcher's, scholar's or designer's intentions in this regard. Gorbet, for instance, provides some arguments in support of this claim [85] (p.114), and since there are particular requirements for these two last properties – *interactivity* and *responsiveness* – a stated specification represents the only way of proving their fulfillment.

The instrument's *real responsiveness* – the one in which the machinic action actively partakes in a dynamic feedback loop at multiple levels – has been defined as a proactive ability to influence and change its relationship with the environment, both shielding from the invasive environmental properties and modulating their values through two-way feedback mechanism, while also transforming and modifying the *instrument*'s architecture itself as a mode of communication and aesthetic experience. The mutual adaptation of two systems – environment and the cluster of tracked objects on the one side and the *architecture-instrument* with its active response on the other – is the only relational mode that fulfills requirements of the *real responsiveness* and, more precisely, *interactivity*. Since interactivity is still relatively underdeveloped and left for improvement in the next stages, the following paragraphs will specify its main distinctions in order to determine design aims and requirements in this regard.

> *... the interaction must be circular, or else the system is merely 'reacting' and not 'interacting.' (Haque, 2006; [5] (p.124))*

> *... there is a clear distinction between reactive communication (sent message is only affected by one) and interactive communication (messages not only sequentially react to each other, but also depend on the history of earlier received messages). (Rafaeli, 1988; [84] (p.205))*

Interactivity usually implies the active role of the supposed input agent in the communication and control feedback system along with the activity of the constructed dynamic system itself (in this case, the *Exo* tracking instrument). It is based on a reciprocal relationship between the systems in interaction and inherent learning processes in both (following Jaskiewicz's notions, [84] (p.205)), or in their *constantly evolving relationships* [86] (p.3). The systems in dialogue and their actions have to be mutually dependent or, in other words, constitutive for and transformable to each other. The human behavior or any artificial behavior and dynamic impulse from the environment (tracked properties), are taken for the input information and the initial signals for the machine's response, while both sides are also assumed to follow the transformation of the other and respond to it accordingly, by changing their behavior or performance. *Interactivity* also implies the existence of the common communication platform between the systems – the *interface* – which enables them to sense and process received stimuli, so as to provide a proper answer and reaction (voluntary and creative (proactive), or involuntary and provoked). In *computed systems*, the *interface* has an important mediating role, such that it presents different information in the form that is transactive and intelligible for participants/systems/components on both sides of the process of information exchange and interaction. For Nicolas Negroponte, who especially developed the term, the *interface* implied a "feedback loop of an object to be sensed, a tool with which to sense it and a mapping of its result for a new or different use" which he (in that particular order) equated with the notions of the "event", "manifestation" and "representation" [27] (pp.173-174). In this light, the proposal that the *architecture-instrument* is at the same time an *interface* (since it integrates all of its above-mentioned components) comes as a viable statement regarding the attribute of *interactivity*. Analyzed in Negroponte's terms, the *Exo-system* also performs in relation to these three notions and operations. The "event" that should be tracked by the sensory system (the external sensory data - in this case a particular frequency, thus certain object that emits it) is first converted into the designed "manifestation" (the whole instrument and its spatial and programmatic structure) as an outcome of the need to make the "event" comprehensible, qualitatively and quantitatively evaluated, and deployed for some purpose. Also, it is converted into the designed "representation" (the instrument's performance and kinetic response, or the activation of the frequency shield as an active disturbance of the invasive impulses from the environment) as a signifier that the "event" has been mapped and processed according to the programmed scientific procedure (the explained relation could be superimposed to the system elements in Fig. 6).

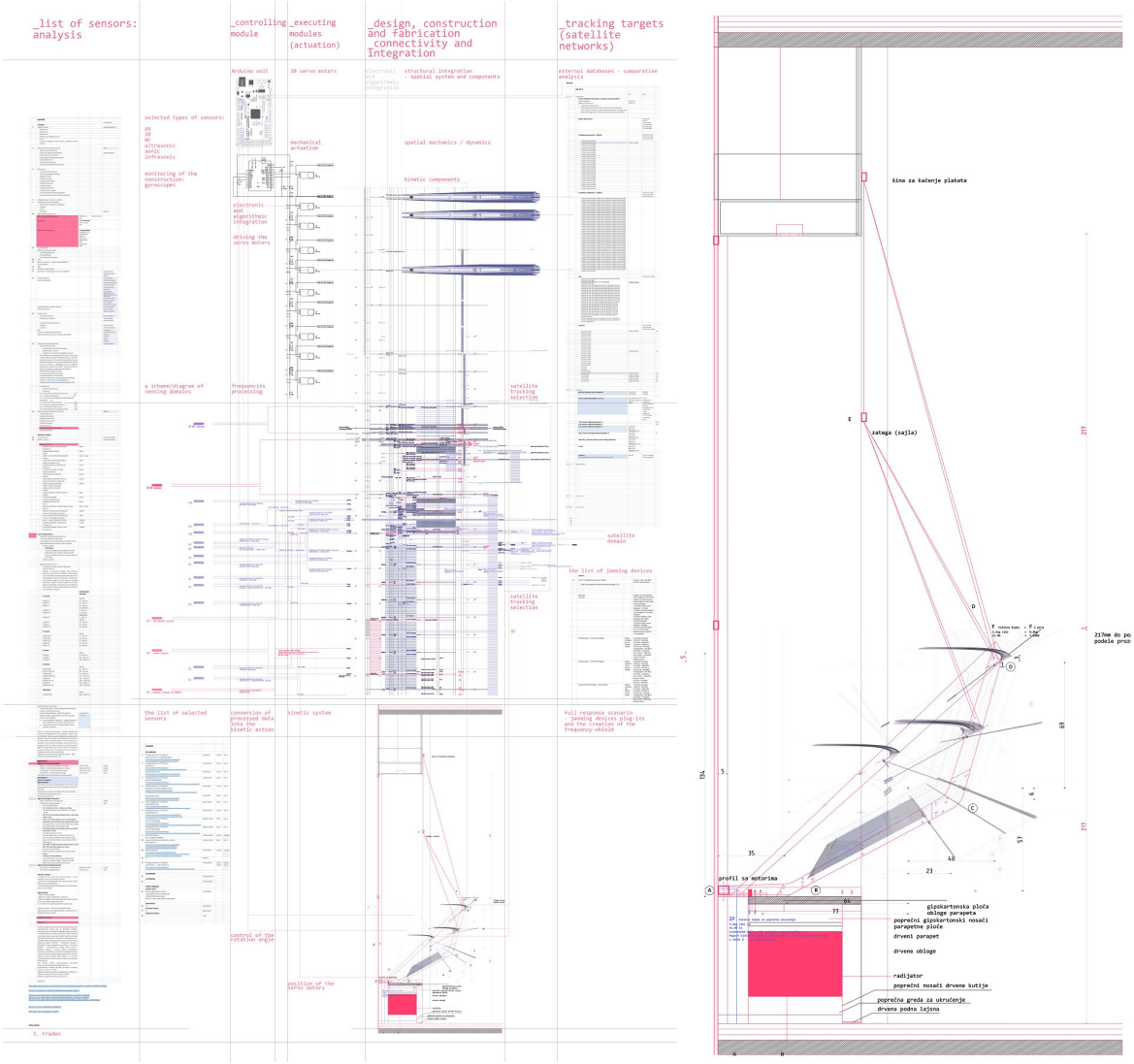

Figure 6. *Global Eye(s)* pilot project and *Exo* prototype experiment, Author and Researcher: Dragana Ćirić ©, 2018-2019

(a) Analytical table representing research procedures performed in regard to the project's methodology and plan of realization, framed according to (1) operations and operating units of the instrument's design, assembly, and systemic integration, and (2) research, data-acquisition, design, and networking of the instrument's components in line with their performances and roles they play within the system. **(b)** Drawing and diagram of the instrument's architectural and structural analysis (simplified construction and static scheme and a cross-section superimposed with the perspective section-view from the 3d model), spatial configuration, and final form designed for the staging at the *Gallery of Science and Technology*, SANU Belgrade, as a part of the program and artistic selection of the *Exhibition and Conference 'On Architecture' 2019*, December 4-16, 2019, Curator: Ružica Bogdanović, STRAND.

The input information in the *Exo* experiment would come from the artificial objects (e.g., satellites) which can be tracked by their signal emissions. Due to their dynamic behavior (the state of movement or change in the signal value) and complex interferences within the environment[7] [87] (pp. 34-35, 22)), the response has to be programmed to embrace constant change of the input information. In that respect, it is said that this variable input information and dynamic behavior shape and modify the characteristics of the *instrument*'s actions in each iteration of the analysis, and consequently influence the kinetic movements. Even though such a scenario has been a part of the design plan, the *real interactivity* hasn't been the subject of the *instrument*'s first phase of development – the argument of its *kinetic performativity*. Only the final stage (the 'frequency shield') which hasn't been tried and tested yet, will be distinguished as a *real interactive responsive architecture* as it has been defined *by design* – the architecture capable of inducing reciprocal anticipations in both the *instrument* and tracked artificial objects (or rather their expression within the system). Thus, a clear designation related to the concepts of the *responsive architecture*, *interactive architecture*, *intelligent environment or architecture*, or *smart architecture* in their full meaning, will be made after all the phases have been accomplished and proved in practice, beyond the sheer theory and the design action plan.

Interactivity and *responsiveness* usually work in pairs.

7 – at least fluctuating and slightly variable if not highly unpredictable considering the physical conditions of their orbiting areas and the environmental phases that their emitting signals encounter and pass-through –

They both imply an active state of the object (*instrument*) which is contained in its ability to respond to the given conditions or external signals in a deliberate manner (*responsiveness*) and to incite change (that will alter the input information) through its interference into environment[8], thus setting in motion the sequences of "conversational actions" (*interactivity*). Both environment (anything external to *architecture-instrument* in the broadest sense, already containing other systems or subsets of objects that could be targeted for observation) and *instrument* are considered to be in a *complex adaptive systems relation*. This implies a high degree of openness and influence on each other's properties, and operation of both systems through the exchange and shifts of states of equilibrium and disequilibrium. Considering the *openness*, however, the system's inner control unit retains the ability to calibrate its degree as required, and the instrument doesn't always have to be in a fully-interactive mode but only when a critical threshold has been breached and when it has to respond to the registered and recorded conditions in a more obtrusive way.

When returning to historical references and first examples of *the responsive interactive ideas in architecture*, or *interactive architecture* (*iA*, [32] (p.3, pp.46-48)), Cedric Price undoubtedly comes first. His project for the *Fun Palace*, followed by that one for the *Oxford Corner House* and the *Generator* [27] (pp.127-163), used and sequentially improved *responsive interactive logic* and the concept of *intelligent architecture* in regard to their visitors, including also all possible kinetic instruments and structural solutions, machine and electronic integration and control that pushed the objective of transformability to the extremes. His dynamic architectural settings assumed an active influence on the visitors inasmuch as the visitors had an active role in shaping the architecture itself (the users' movement paths and requirements represented the input information for the architectural change). *Fun Palace* proposal starts with the loop: "Input of Unmodified People" > interaction with space and "Actual Network" (entering and taking part in it) > the "Output of Modified People" [27] (p.132). Such a one-way transformative force has been advanced in all the subsequent projects of his *teaching and conversational machines at the scale of architecture*. The interactive responsive architecture of the *Oxford Corner House* [27] (p.146, pp.141-147) realized these attributes within the registers of information and media, while the *Generator* made a step forward by changing personal interactions within its responsive, reconfigurable architecture [27] (p.147, pp.147-161) and by developing the notion of the environment itself which has become the intelligent artifact – "a networked site that could learn from and challenge its users" [27] (p.147). The *Generator*'s human-computer-architecture relations represented the highest stage of development of the Price's initial idea of pervading the whole architecture with the electronic sensing, processing, and decision-making systems. The technical solution of the *intelligent performance* of this space (resolved by the expertise of John and Julia Frazer [27] (pp.156-160)) hasn't been based only on passive learning from users, their desires and voluntary operations inside of it, but it has been challenging them by demanding constant interaction under the *Boredom Protocol/Program* [27] (pp.156-160). *Interactivity*, therefore, has constantly been provoked, while the concept has brought the very convergence of the *intelligent performance*, *responsiveness*, and users' participation in architecture to the level of excellence.

In conclusion to this section, *Exo* could be commented regarding the subject of observation (the *environment* or any *external system*) and its relation to it (a degree of cybernetic openness) as important parts of their predetermined "conversation" protocol. In this respect, the experiment specifies itself within the field of *environmental sensing*, as adjacent to the field of *human-machine interaction* by using the type of the *machine-to-machine exchange ('architecture-machine'-to-'environment-machine' transaction*) and solutions that could detect even the most sophisticated and covert systems of the artificial kind. Its *adaptation* mode (determined by *responsiveness* and *interactivity*) is composed in relation to other artificial objects within the environment, not humans directly, even though humans could also be involved depending on the research methodology that defines a network of devices used for data-acquisition or detection. *Exo model* is based on an *interaction between the machine and the machine*, while the system, regarding its high degree of openness (which conditions the possibility of interaction, too), can be easily reprogrammed and expanded with additional sensing capabilities and other information sources. Expanding the range of data-sources that involves humans and their sensing devices (*coded objects* [31]), reconceptualizes participants as *human—machines*. The human participants become the secondary carriers or mediators of information by pairing with devices and software they use, thus reconfiguring the relation between the instrument and the environment, which in this case can work through *'architecture-machine'-to-'human-machine' transactions*.

4. Discussion

A discussion can include a few short issues regarding the course of the experimental work and the methodology of the experiment and prototyping in general, referring above all to their iterative investigative phases and tests of the proposed architectural designs. As it has been explained, the supplementary material presented through illustrations and videos has been obtained from two exhibition settings

8 (whether by provoking a reaction from apparently fixed external systems or by perpetuating the change of their already variable properties by adding the values that it emits itself)

which have worked as environments for delivering the proof of a design concept and systemic integration at the architectural and structural level, targeting in particular the *instrument*'s kinetic operation, static and dynamic behavior. Here, the simplest modes of automation and command-and-control algorithms (sufficient for their proper operation) were applied, while primary data-sources for this first phase of tests were online data-bases and specialized software for satellite tracking. Since the advanced forms of the internal sensing system and the algorithmic system (aiming at its *intelligent mode*) demanded special designs, new technical solutions, and even patents, they have been left for later stages of the project's development, both as independent components and as parts of the *Exo-system.*

Exo's next phase will aim towards full application and execution at the level of *real responsiveness* and *interactivity*. Completely equipped with all sensors, computing boards, and kinetic actuators [5] (p.116), the installation will be enabled to react and interfere with the environment according to pre-programmed protocols. In addition to this, one of the prime investigative objectives that needs to be practically resolved will include the question of the embedded *machine intelligence* which significantly differs from the sheer *automation* applied at the present. The attribute of *interactivity* still has to be reconsidered as a nuanced kind of *responsiveness* and more clearly outlined in regard to application and performance. At this stage, it has been present through interaction between the designer as a moderator of the instrument's tasks and operation and the *instrument* itself (its reconfigurative geometry and inner evaluative processes), as well as between them in the form of an integrated system and the *environment* through awareness of tracked parameters and artificial objects external to the instrument itself. This kind of interaction hasn't been solidified yet, due to the both openness of the model for the purposes of the continued experimentation and artistic performance-based requirements. The analysis of the *Exo*'s premises and prospects against the extensible *multi-agent interactive architectural meta-model* (*xMAiA meta-model*, [84] (pp.206-208)) might also become informative regarding investigated issues.

5. Conclusion

The architecture based on change (dynamic and temporal determinants) claims several historical phases of development, along with its design aspects present and transferred as constant categories. Dependent on both passive and active technologies used for situating the architectural system into the temporal design framework, or setting some of its components into the direct motion, design approaches have changed as well. The age of the mechanical motion has lasted the longest, and three machine ages distinguished by Perry [13] (pp.192-193) explain the course of the most recent developments that finally led to today's technological convergence in terms of responsive operational modes and systems in architecture. Advanced theoretical and practical achievements have been historically recognized as constitutive and decisive for issues of dynamics, adaptation, programmability and kinetics in architecture. However, when analyzing the progress of these issues, it is the integration of various disciplines, design and engineering fields required for making such architectural and artistic ideas possible at the level of the technical excellence well-known and applied today, that is the most important. The set of events within the field of experimental arts, architecture, sciences, and technologies (concluded with the 1968 exhibition "The Machine as Seen at the End of the Mechanical Age") [35] has been claimed to have marked the shift from the *mechanical* to the *electronic era* - from the imitation of our muscles and motoric/kinetic performances to the imitation of our brain and nervous system. The interdependence of both, including their integration with sentient abilities, however, discarded such strict division and the view of the clear-cut successive shifts of paradigms. The 1969 coinage of the term *mechatronics* [21] (p.21), for instance, implies the start of one of such convergences, eventually arriving at what we perceive today as *comprehensive mechatronic systems* [21] (p.25), variously explained in literature and applied in practice with arguments of the problematized disciplinary integration [21, 88 (pp.v-vi, 1, 1157), 89 (p.ix), 10 (p.v)]. Even the architectural examples at the beginning of the cybernetic age, which have investigated systems design, inclined towards a disciplinary synthesis, and the most recent ones, based on contemporary innovations in *robotics, mechatronics, architectural sentience, kinetics, responsiveness and interactivity*, conclude the notions about their true convergence. These recent examples combine mechanical, electronic and microelectronic, algorithmic command-and-control, and sensory systems or attributes in construing new forms of *comprehensive architecture-machines*. This is done in a manner that finally and fully realizes the applications anticipated back in the 1950s and 1960s, and it also drives a number of new applications and patents. The additional extension of the design domain with inclusion of biosystems and their properties (e.g., evolvability, or evolutionary adaptability), environmental engineering, materials science and various degrees of intelligent performance, furthers the complexity of possible solutions for such systems and their performances.

From the perspective that binds arts and sciences, as Arthur Miller has been able to summarize [90], and based on the evidence supporting it through numerous historical resources and current practices, disciplinary convergences required for investigation and design of complex systems deny any such point of view that features only one of the aspects. *Systemic architecting* demands integration of a larger number of research fields, professional and theoretical knowledge and skills, and current cultural

mindset reveals that such integrations are always present regardless of the narratives of grand shifts and radical turns [91, 92]. Such narratives are usually based more on the pragmatic application strategies than demands within the research environments dependent on collaboration, and this is why they might fail regarding consistency in both theory and practice. Disciplinary convergence represents an important and necessary condition. Its absence from the very course of the research might cause major setbacks in the design's progression, and leave some aspects unresolved.

The concepts that enable architecture to perform specific scientific and artistic tasks in a highly sophisticated manner and in addition to its basic determinants, as well as to express them in time, have been analyzed and presented by the attributes they instill into the architectural objects - *sentience*, *dynamics*, *kinetics*, *smartness* and *intelligence*, *performativity*, *responsiveness*, and *interactivity*. Such features induce innovation in architecture, having been designated as formative for some of the more complex outcomes and performances that the architectural objects are made capable of expressing. The attributes are at once the key for determining the position of one's architectural design within the theoretical framework (e.g., within the *kinetic art or architecture*, *performance design*, *performative architecture*, *responsive architecture*, etc.) and for the clear statement of the design's category or spatial format. In this respect, several formats have been proposed for investigation – *architecture-instruments*, *architecture-machines* or *architecture-robots*, *architectural prototypes* and *architectural installations* – considered as stand-alone objects, systems or subsystems, and abstract procedures. In line with their spatial frameworks, and with regards to central attributes and performance tasks that have become inevitable aspects of contemporary architectural thinking and practice, the character of *programmable,* d*ynamic, kinetic responsive architecture* has been particularly targeted as an outcome of the proposed integration at multiple architectural levels.

In the case of the *Exo* project, the set of characteristics that were analyzed were, at the same time, its basic operative requirements and advantages in comparison to standard architectural objects, design strategies, and procedures. Nevertheless, they have also represented the means of realizing its research goals and getting the proper contextualization within the theoretical and critical discourses in architecture. The relevance of the *Exo*-experiment and project, regarded as a *spatial setting* (*architecture* or *object*), *system,* and *abstract logic of operation and design*, lies in its ability to investigate and test different solutions at the *microscale* (in a form that has a smaller spatial coverage), while also retaining the 1:1 design properties. The spatial scale and format of the interior *installation*, *instrument* and *prototype*, resolve the main issues of architectural systemic integration of operative attributes and components responsible for their expression in the most rational way. The chosen dimension of the object, in terms of the physical occupancy of the system as a whole and design of each component, represents the well-synchronized result at multiple scales. As a subsystem – the system paired with the existing architectural structures (as it has been the case with the gallery spaces, Fig. 1 and 5) – the object demonstrates the provision of additional functions and aesthetics to the space it has been adjusted to. As a model of a stand-alone architectural space, requiring either appropriate scaling of certain elements or multiplication according to the architectural typology and programmatic conditions in certain development phases, it provides the framework which can be easily modified to fit various spatial demands. At the center, it has certainly been the idea of an architectural system having advanced properties and performance attributes (being cybernetic, programmable, mechatronic, sensing, dynamic, responsive, kinetic, intelligent system). Also, it has been the idea of demonstrating this new class of objects characterized by the described attributes, operating both as architecture and a machine (physical and abstract), or, at the higher level of subtlety, as an *architecture-instrument*.

Exo's logic of operation, the idea of systemic and spatial integration, and the method of design and networking of the subsystemic components (operative modules) towards the posed research goal (Fig. 5 and 6) can be (if brought to the level of universal principles) easily applied to any other similar situation, encompassing frameworks of all - the theoretical research, practice, experimentation, and patent seeking. As such, *Exo* can prove its epistemological, methodological, technical, and didactic contribution, while displaying the proof of an artistic-scientific convergence in all these registers. The plans to invest further research into its more sophisticated and advanced modes of both form and operation will certainly bring discoveries and innovation to architectural and broader scientific and artistic communities.

6. Patents

The experiment assumes development and production of several technical solutions or small patents regarding each of the instrument's subsystems. They include the *Exo* internal sensory system, algorithmic integration and processing, the interface board with frequencies and wavelengths (containing also a possibility to embed some of the sensors within) [93] (p.58), and the kinetic elements as possible autonomous design-objects or sensing objects in some of the proposed versions. On the level of the architectural systemic integration, the *Exo-system* has proposed a technical solution of the *dynamic (kinetic) architectural system* and *architecture-instrument* (a *comprehensive sensing and tracking prototype*) [1, 93 (pp. 59-61)]. Some of the above-mentioned solutions, however, are still in the phase of proposals, concepts, and design plans, and no further acknowledgments in this regard can

be made at this point.

Supplementary Materials

The following are available online at:
Video 1: https://vimeo.com/369772049;
Videos related to Figure 2:
https://vimeo.com/368229565,
https://vimeo.com/368214907,
https://vimeo.com/368224357.
Research project blog links:
https://dciricglobaleyes.tumblr.com
https://dciricglobaleyesfrequencies.tumblr.com
https://dciricexoglobaleyes.tumblr.com
Further supplementary material including Glossary may be requested directly from the corresponding author.

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