[*Exo*] Between the Scientific and Artistic Methodologies: Operating Regimes, or Soft Architecture of the Integrative Responsive Kinetic System

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Abstract

The research on architectural dynamic responsive systems has been conducted through the construction of the experimental architectural installation, object, prototype, or *architecture-instrument* - *Exo*. The instrument has been designed as a part of the specific investigative module on comprehensive sensing, automation technologies, dynamic performance, and their architectural systemic integration within the *Global Eye(s)* research project. With this function, it has been aimed to work as an architectural proof of selected concepts and claims made within the project's agenda, and as the physical platform for further investigations and tests in regard to targeted research subjects. Alongside the definition of the prototyped *architecture-instrument*, its spatial and operative format and technical solution, the attributes that could have qualified certain spatial designs as these types of architectural systems have also been ascertained. The claim of the attributes' operability has been ensured through integration or embeddedness of several operative units and their components into the instrument's system design. They have included (1) sentient unit (the network of sensors selected according to the targeted research objects, alongside the set of components that could substitute their function), (2) command-and-control and data-processing unit (hard and soft elements), (3) motor, or actuation unit, and (4) kinetic architectural unit which finally synthesises all the elements and defines the instrument's physical and mechanical properties (the geometry of both its spatial distribution and kinetic performance). The architecture had represented the major framework and one of the most important targeted fields of inquiry and application of thereby analysed topics and proposed technical solutions, yet the cross-disciplinary exchange, which the presented systemic thinking and design have strongly depended on during the conceptualisation, research and

construction processes, can direct different achievements and developments to adjacent fields of interest.

The *Exo* experimental object and system have been designed following and converging both scientific and artistic methodologies, having the abilities to contribute to all aspects that thereby could have been targeted. This statement refers likewise to its mode of operation, which has partly been subjected to algorithmic control. This paper will put the particular emphasis on the latter - the instrument's plan of operation, or its soft systemic component – followed by the explanation of the artistic and scientific performative regimes and aspects they enable, their automation, and possibilities of raising some of the basic algorithms that have been used for the stage of the proof of a concept to the level of the *smart* and/or *intelligent* performance.

Keywords: architectural dynamic responsive systems, kinetics, prototyping, architectural installation, *architecture-instrument*, *architecture-machine*, scientific research methodology, artistic research methodology, soft architecture

1. Introduction

The introduction will provide an overview of major characteristics and arguments regarding developed and applied design research methodology and spatial format of the presented project. The first part will explain the wider cross-disciplinary framework of the artistic-scientific methodological convergence that has taken the dominant role in shaping most of the recent advanced practices based on investigative creative thinking, design and production, and whose specific framework has been advocated, tested, and proved as tenable by this particular project. The second part will offer a critical summary of the proposed and developed spatial format of the *architecture-instrument*, including all the precedents and formal categories that have been synthesised into such model of the *programmable or computed architecture*, and *architecturally integrated responsive kinetic system*.

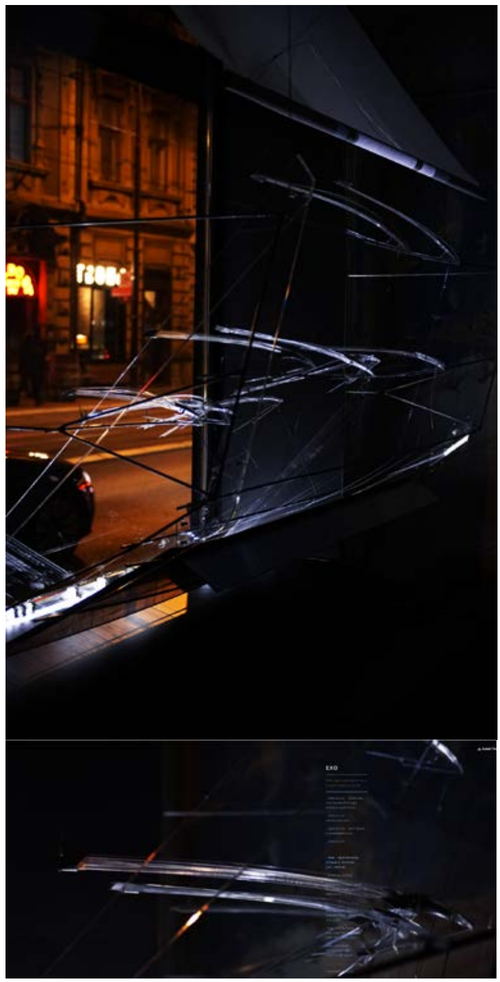


Figure 1 a. Architectural instrument (installation), *Kolektiv Gallery*, 16-28 October

2019, Author: Dragana Ćirić, Curator: Marija Bjelić, Kolektiv Gallery *3m3 series 2019,* Producer: Senka Latinović; Technical Support: Aleksandar Popović; Photography: Alex Murray), b. *Exo online exhibition and related publications – D. Ciric personal blog,* https://dciricexoglobaleyes.tumblr.com/

1.1 Cross-disciplinary Framework: Convergence of Artistic and Scientific Methodologies

Revised definitions of interdisciplinarity, cross-disciplinarity, and trans-disciplinarity, and debates constructed around them in the past two decades, gave more precise frameworks for research and professional design efforts based on disciplinary integrative approaches, objectives, and methods [1, 2, 3 (pp.4-5), 4, 5 (p.3), 6 (p.39)]. They have simultaneously involved questions of methodological and knowledge transfers between different research fields, having a specific focus on possible ways of converging artistic and scientific objectives, approaches, methods, and production [6, 7, 8]. Critical attitudes usually strictly oppose scientific and artistic research and design frameworks as strongly divergent to such an extent that, at times, their mutual coexistence becomes completely disabled. Arts and sciences are by fact and custom formally separated as completely different spheres of thinking and action - they belong to different areas within the disciplinary system. But, alongside the plausibility of these statements in regard to the largest part of artistic and scientific practices and education, the higher meta-level of disciplinary exchange and collaboration poses a serious challenge to these basic distinctions, demonstrated through the number of recent experiments and studies. By constructing specific research frameworks which finally justify and confirm the claims of scientific-artistic convergence through projects realisations, they prove the opposing arguments completely untenable for certain cases. Contemporary attempts to scientifically reinforce artistic practices, the involvement of highly specialised and scientifically competent individuals in artistic research and modes of communication, or the engagement of large teams in artistic production on the one side, as well as the enhancement of scientific communication and procedures through artistic creative intellectual processing, representation and extended sensory experience on the other (including artistic collaborations with scientific laboratories), have all contributed to the development of new hybrid research and design forms. This perspective has long been present in history – the connection between the artistic representation and scientific facts, empirical observation, and explanation has long been inseparable (e.g., Leonardo da Vinci's collaboration with Luca Pacioli [9], his detailed investigations, observations, and representations of natural phenomena and scientific facts from various disciplines [10], Agostino Scilla's artistic contribution to science [11] (pp. 125-126) and many others). The break and divergence have been brought and enforced upon such formal organisation by the modern disciplinary system, established rules of categorisation, and division of practices, while in the current moment, they have encountered a new revision and another assessment of proper responses by new advanced artistic-scientific practices.

Figure 2. Global Eye(s) design research framework – web presentation and blog of the author comprising the project's complex branching, with investigated themes, papers and publications, exhibitions and overall research results (https://dciricglobaleyes.tumblr.com); subsection (scientific research) *Frequencies* (https://dciricglobaleyesfrequencies.tumblr.com/) and artistic presentations (https://dciricexoglobaleyes.tumblr.com/)

The author positions herself and her objectives within this small and privileged group of experiments by recognising common threads and planes of artistic and scientific methodologies within her integrative, cross-disciplinary and systemic spatial design research approach. The contribution of the *Exo* experiment regarding such discourse has been reflected in its successful deployment of both methodological lines and deliverance of yet another proof of accountability of their convergence. The project represents the smaller part of the author's initiative for the new framework for innovation in architectural research and practices through laboratory organisation, which she has been advocating and programming herself since 2018 in absentia of the better institutional infrastructure and framework for the presented objectives and project development. *Exo*'s specific integration of spatial and architectural design, comprehensive sensing and sensory technologies, software design, computer and information sciences, electronics, mechanical engineering and robotics, all towards the creation of digitally, sensory and kinetically augmented performances of architectural spaces, their embeddedness into digital infrastructure and environmental awareness, truly represents the example that stands out in such an idea, having several registers of potential technical development, alongside providing the platform for critical examination of such disciplinary convergences and consequent spatial results.

In commented artistic-scientific convergence, architecture has a specific place. A large number of architectural schools throughout history have been defining their agendas by inclining more towards either the arts and humanities, or towards the status closer to the mathematical and engineering sciences, or at least they have rendered stronger identity in certain parts of these two poles. Difficult position of architecture in this regard, undoubtedly requiring both for desired architectural excellence, maintains even today, even though the pedagogical context is much more complex. It destines the orientation of architectural schools in response to the requirements of taking proper theoretical, practical and professional lines and profile of development and teaching. The attitude of the author against certain forced discordances and divisions in both advocates and executives of such agendas and educated individuals, has been made upfront. The number of outstanding practices that move the architectural boundaries and excellence prove the importance of comprehensive and extended spatial knowledge.

The first problem that appears in all the attempts to integrate or confront scientific and artistic approaches and labels, refers to their differing frameworks, objectives, tools, methods, modes of problematisation, application demands (function or utility), and registers of their conduct and communication. Scientific approach (even in arts) will most certainly demand the highest precision of scientific methods, complete accuracy regarding data acquisition, and lead experiments to applied forms and industrial production alongside aspiring to provide sound and reliable scientific knowledge. Applied forms also require more robust legal frameworks and production requirements, teams of review experts, professionals, and advisors, with a clearly defined function, aims, feasibility studies, and financial plans. *Pure arts*, on the other hand, might try to distance themselves from any kind of profit-based (commercial) and industrial production-based models that are frequently at the very center of the artistic critique (excluding those highly involved in today's art market). They might also argue a distance from the utilitarian design aspects being confined primarily to the artistic ideas, concepts, and aesthetics (e.g., Jean Tinguely's dysfunctional or non-functional machines). Focused on aesthetics and experiential effects, ideation and strong message, and individual experiences and skills that contribute to some intimate or objective conclusions, arts may try to stay sincere and honest with the subject of investigation (to uncover, tackle or provoke some oftentimes controversial issues), as well as they could adopt a more playful, intentionally decisive, or dramatized positions [12] (p.). All these hardly adhere to the world of sciences, which aims to prevent and reveal all the potential fallacies behind such effects, not having their aesthetic perpetuation as an objective as arts do.

Besides such facts and appearance of artistic-scientific methodological unrelatability or divergence, the operative frameworks of their convergent forms do exist and can be constructed. The questioning can be further directed towards the experimental forms that can resolve such issues if referring to architecture as a discipline that clearly converges both aspects in its profile, theory, and forms of action. Even though some claim that "architects who have an interest in experimental form-making or even theoretical [urban] (parenthesis added) critique leave building practice and move full time into the world of art installations, writing, or drawings for the gallery" [13], the truth behind this choice contains the same responsibility like any other architectural commission, being even more research and scientifically demanding, and sometimes representing that parallel track which significantly supports and advances the regular architectural practice and theory. Their smaller scale doesn't make them less significant, especially regarding the fact that they enable and usually bring certain innovations to the whole practice. The efficiency in practice mostly relies on the application of already acquired and confirmed knowledge, available and attested products chosen according to predefined design objectives, while experimentation precisely challenges and questions here present conventions with the aim of going beyond their current status towards the improvement of the overall design performances. In other words, experimentation offers more flexible forms of architectural expression, and spatial formats for innovative design strategies with the particular emphasis on critical revisions of architectural standards by "offering alternatives that highlight weaknesses within existing normality" [14] (p. 35). Oriented towards innovation and invention, it is still for the purposes of building, reflecting upon it and constructing new knowledge through design research. Experimentation and prototyping could be used as a testing ground for bigger design commissions or their particular registers (such as detailing, software integration, construction and formal solutions, introduction of the new social/cultural/environmental issues or innovative technologies, structures, or formal geometries). The difference that might further appear in this regard could be related to the professional context and organisation of the experimental work. This refers to situations that either engage the whole teams of practice-oriented engineers and market-experts within the industrial environment, or those dependent on art/experiment-specialised and perhaps more delicately science-oriented individuals, their skills, inventiveness, and discoveries that will also, finally at a certain point, be brought to the building practice and industry.

Artistic forms within the architectural or other design disciplines have been questioned mostly regarding the pragmatic and commercial side of their application. On the other hand, it has been stated that direct connections to industry and patent seeking have been seen to undermine the role of the traditionally construed arts and humanities across the universities [15] (p.109). The material object-like applied forms (prototypes, technical solutions, or patents) have been opposed to their critical, speculative, artistic counterparts. But such strict borders between the industrial and commercial design approach on the one hand and the artistic approach on the other do not have to be so rigorous. Dunne and Ruby see artistic and aesthetic aspects as invaluable critical means to values claimed and entertained in profit-oriented market-driven industrial production and design (*critical*, *speculative,* and *conceptual design*, [14]) while the scientific high-precision research results can significantly contribute to technical firmness of any form of artistic experimentation. Such integration could lead to better results and more insightful and self-aware conduct in design considering both sides. The architecture with its position in-between the two can contribute to the resolution of their disbalances through its own example.

1. 2. *Architecture-Instrument*: New Spatial Format and Design Research Methodology

The hypothesis of integration has also been contained in the convergence of the form of the technical solution or small patent related to the scientific line of investigation, and different exhibition formats (spatial installations and staging among others), more freely approached from the artistic perspective. Eric Nay offers some thoughts on the subject [15] (pp.108-104). He comments on the inaccessibility of the patents and technical solutions to the wider public due to their scientific closures and at times covertness by contrasting them to arts and humanities' practices that, while aiming to communicate with their audiences in an open and interactive way, produce documentation and evidence (books, catalogues, exhibition artifacts, performances, dialogues, etc.) that make important issues and problems visible, accessible and widely comprehensible. The aim to overcome certain disadvantages in thus divided settings, alongside those that Nay has identified, and to reconcile these distant or unrelated formats, has been at the core of the *Exo prototyping methodology*. The objective has been reflected in a complex assembly of models for the scientific and artistic research within the proposed *architecture-instrument* format and framework.

The spatial research and design models, that have been inquired and interchangeably used, comprise the following: analogue operative model, prototype, technical solution, patent, spatial installation, instrument, machine, device, and exhibition forms including detailed analysis of all their subcategories and disciplinary- or context-defined and directed forms. Several papers have explained the path that has been taken to get to the proposed format of the *architecture-instrument* [7, 8] including discussions on subtle differences between all the listed categories in relation to the posed artistic-scientific opposition, or convergence, especially the formats origins in machine-like objects and systems, or *architecture-machine* concept [8]. One can rely on their arguments and explanations if trying to go deeper into the debate and challenge some of the propositions, while some of the most important methodological insights will be commented on in the following paragraphs.

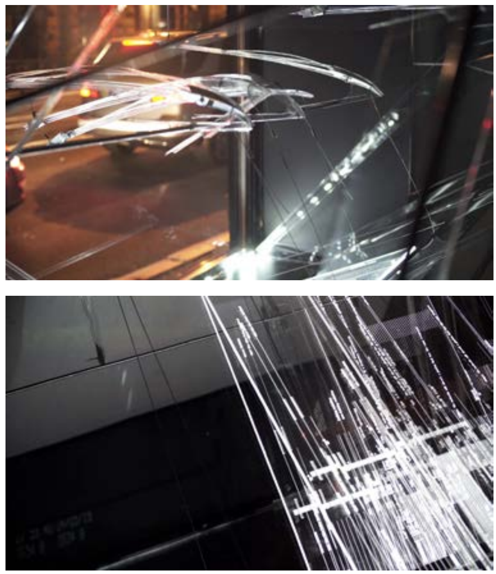


Figure 3 Installation/exhibition *exo [global eye(s)]*, Kolektiv Gallery, 15-28 October, 2019. Stills from a video material by Alex Murray ©, postproduction and editing Dragana Ćirić, https://vimeo.com/368229565, https://vimeo.com/368224357, https://vimeo.com/368214907.

a. Kinetic elements and mechanism. b. Detail of the diagrammed plane and the mirror-plane during the video projection of the SpaceX CubeSat launching 24 May 2019: *The train of Starlink satellites passing over Leiden, the Netherlands, about 22.5 hours after launch.*

Video with WATEC 902H + Canon FD 1.8/50 mm lens, GPS time inserter. Source: Marco Langbroek, Leiden, the Netherlands, https://vimeo.com/338361997?fbclid=IwAR0uwSPEOhncgJg7lzKU2COXYArzHlSBKoiN0arT7zgHmiuCQS7vJkHTA-E

Considering the methodological framework roughly positioned within the broader field of *design research methodologies*, the methods that have provided the basic investigative procedures have included experiment, simulation, prototyping in general with industrial prototyping, sci-fi prototyping, and physical fiction as some of its branches, alongside design and modelling. They have been used in a combined and mutually complementary form to prove and test argued objectives, and some of the insights and important conclusions of such research approach will be added to this analysis.

Experimentation usually applies to innovation, product or a procedure that needs to be tested, to situations whose consequences have to be checked, to scientific methods working as means of proof. More formally, belonging to the empirical studies based on the derivation of evidence from direct and indirect observations and experience [16], *experimentation can be defined as "a recording of observations, quantitative or qualitative, made by defined and recorded operations and in defined conditions, followed by examination of the data, by appropriate statistical and mathematical rules, for the existence of significant relations"* according to Nesselroade and Cattell [17] (pp.4-5). It is used to test predictions and hypotheses, for theory building, for reliable scientific knowledge construction from direct experience, and usually based on rigorously planned and controlled conditions of conduct in order to come up with the most clarifying insights and reliable data. Alongside these features, the prototype-properties condition an additional demand for production of the functional object, not allowing that the epistemological contribution becomes the only outcome of the experimental process. The result is therefore directed towards the fully operational form in line with scientific documentation and conclusions coming out from the experiment.

Spatial design and modelling methodologies have been applied in part that controls the spatial, architectural distribution and integration of all the systemic elements (Figure 4). The used components have been architecturally integrated the same way as it is done in architectural objects design and architectural design process. Design strategies and methods provide the most refined equilibrium regarding theoretical and knowledge-based concepts, technical requirements and stability, and aesthetic qualities. The fact that the kinetic performance of the instrument has added new dynamic interactions into the system of standard static and dynamic forces, made the prototyping research more challenging and exciting, demanding closer collaboration with adjacent disciplinary fields (e.g., mechanical engineering), while the electronic and algorithmic command-and-control components implied inclusion of even more fields of expertise (electronic engineering and programming). The sensory network and software integration, along with the dynamic system's design have directly become architectural concerns, and have implied the necessity of gaining certain knowledge in these fields as well (Figure 5). The part of the methodologies related to modelling and fabrication made the crossover to industrial object design whereas the usual architectural skills in 3d modelling and design have been applied to smaller scales and detailing.

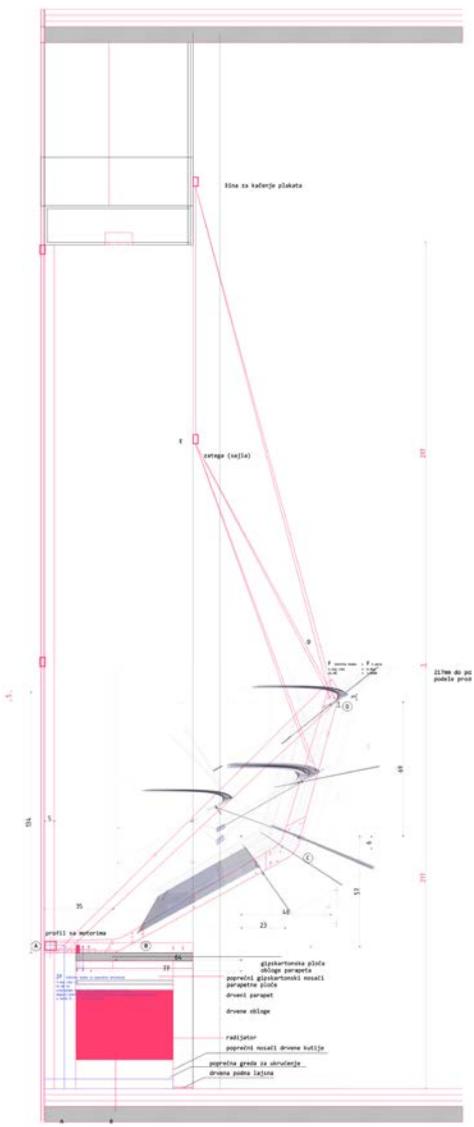


Figure 4 Drawing and diagram of architectural and structural analysis (simplified construction and static scheme and cross-section superimposed with the perspective section-view from the 3d model) of the proposed spatial configuration and its final form designed for the staging at the *Gallery of Science and Technology*, SANU Belgrade, 4-16 December 2019, Exhibition *On Architecture 2019*, Author: Dragana Ćirić (Curator: Ružica Bogdanović, STRAND).

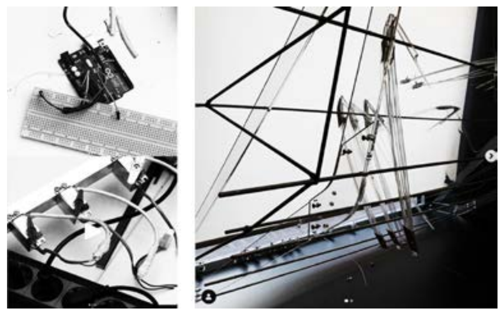


Figure 5 Exo components' site-specific assembly. a. Arduino microcontroller and electronic integration and the architectural montage of servo motors. b. bearing construction and kinetic components ("feathers"); *Kolektiv Gallery*, Author: Dragana Ćirić; Software integration, electronic and technical support: Aleksandar Popović (Karkatag Koletiv); Photography: Nikola Abramović

Exhibition design, production, and performance methods have been used as means of artistic representation, practice, and experimentation. They have supported and intensified the communicative and aesthetic registers of the project's presentation, and thus mediated scientific ideas, questions, problems, and information through artistic modes of expression (Figure 1 and 3). The concepts from scientific inquiries have been properly translated and transposed to artistic discourse, not losing their reliability and precision considering the scientific function. The created form of *mise-un-scene machine* [12] and spatial installations was supposed to differ from usual artistic constructions in terms of operational aspects and functionality in delivering plausible information. In this regard, the final performance delivered according to the algorithmic programme has been enabled to follow two modes – the first one presenting the kinetic choreography as a direct translation of scientific input data for predefined objects, while the second has been based on the unknown subject of research whose activity has been registered, identified and made intelligible through movements of the instrument's kinetic components.

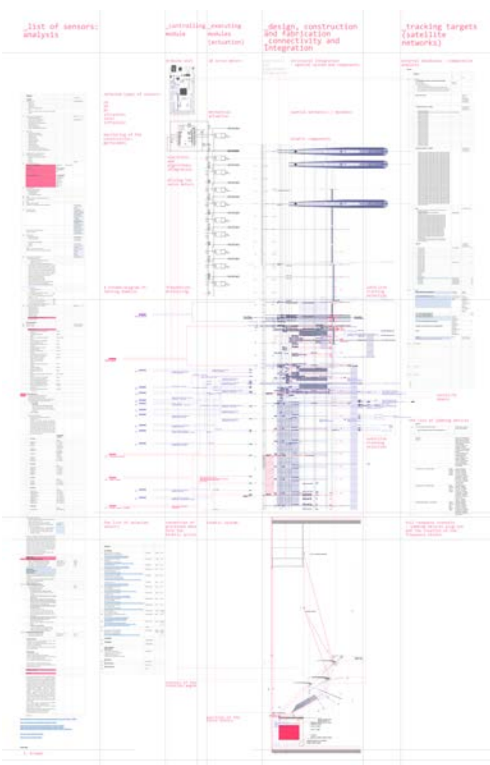


Figure 6 Global Eye(s) pilot project and *Exo* prototype experiment, Author and Researcher: Dragana Ćirić, 2018-2019, (a) Analytical table representing research procedures performed in regard to the project's methodology and plan of realisation, framed according to (1) the operations and operating units 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.

The narrative background has also been presented following two tracks, each corresponding to either artistic or scientific register. The artistic one has been based on the scenario—making *sci-fi prototyping* and *physical fiction* [14, 18], all also widely used in various practices dealing with future technologies and predictions, while the scientific track has retained the research rigor and systematic way of planning, networking, and execution of the project's investigative phases, securing the reliability of data, the integrity of data-acquisition process and content that will be artfully mediated, the construction and proper integration of all systemic components, and architectural or spatial integrity of the final object (Figure 6).

The conclusion to the first section can put an emphasis on definitions derived for the proposed *architecture-instrument* format, based on all the investigated sources, operational, structural, and geometric qualities of this specific class of spatial objects and *Exo* experiment's tests and profs of the starting claims related to all the above-stated issues as part of the still unpublished material [19]:

> "The term *instrument* […] can be used twofold. The first refers to the scientific context and high-precision

machine which can provide reliable data or scientific facts, thus expressing use-value according to the procedures it performs, parameters it measures, problems it solves, and programmes and protocols (…) it follows (and executes, emphasis added). The second unfolds within the artistic context where it can be designated as a device capable of producing and reproducing the content or an effect (and experience, emphasis added) of a specific artistic and aesthetic value and impact, while also entailing a distinctive critical and speculative potential corresponding to means and technologies by which they have been mediated." [8] (pp. 462-463).

While the Exo experiment has tried to reconcile these separated designations by using both artistic problematisation that often deploys dramatisation (*mise-en-scène machine tactics* and *staging tactics* [12] (p. 110) that can more or less alter the real conditions in favour of the art communication and interpretation), and the scientific rigour of the instrumental approach that has to be grounded on reliable data and precise measurements (without any kind of their refinement or altering due to the desired aesthetic effect) – the attributes that are the main research subject of this study largely influence and enable different ways for this to be achieved. By combining precision, technical and technological excellence, operative results and data coming out from the scientific approach, and the highly valued sensory experiences, communication, and representation alongside the specific kind of intellectual incitement coming from the artistic and creative disciplines, these properties can better mediate their complementary work and outcomes.

"The *Exo* experiment used the *architecture-instrument* designation to bridge the gap between the aspects of an artistic didactic and speculative device (staged in the form of an installation and certain subcategories of an artistic prototype [14]) and those of a reliable technical solution (the *applied scientific design prototype* enabled to perform demanding scientific operations). It aimed at merging the artful critical and aesthetic analysis, performance and communication, and the scientific testing performed according to a particular research methodology. Placed between the industrial (scientific) production (based on prototyping and object design methods) and artistic thinking and creative approaches (highly concerned with unbiased aesthetics and critical thinking, unsusceptible to commercial preferences), it managed to confirm the initial hypothesis of convergence of these formally distant methodologies. It has been claimed that they can both enhance each other in certain parts, rendering a greater degree of refinement in either scientific or aesthetic register" or both in their complementary form (emphasis added). [8] (p.464) [18]

2. Exo Project and its Research Framework

2.1 Project Description

A more detailed description of the instrument's performance has been provided in several papers. In order to maintain the economy of writing, the section will make references to them [7, 19], while giving a more elaborate explanation in the live presentation.

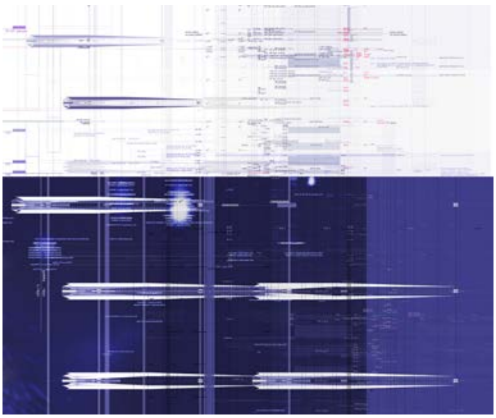
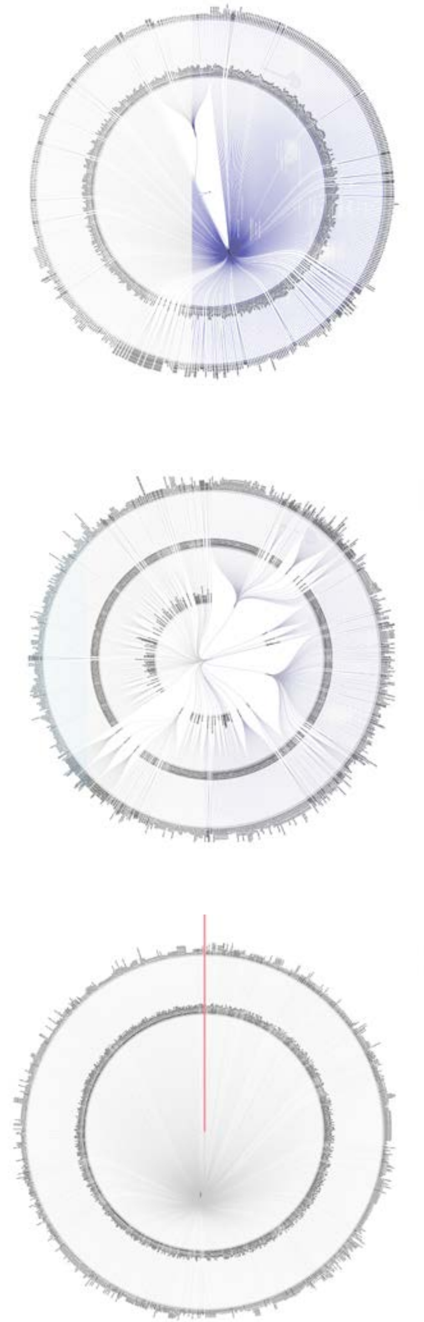


Figure 7 Details of the scale-diagram of frequencies and wave-lengths (0Hz-2.4×10^{28}Hz) superposed by information on functions and objects operating in specific domains – within defined bands or channels – in line with the several national and international standards, according to which kinetic components of the instruments – "feathers" – have been calibrated so as to register, identify and track the activity in the assigned domain or frequency value. Scientific scale-diagram (background image in fragments, 2018) and graphic postproduction for the exhibition (the resulting image, 2019): © Dragana Ćirić (the part of the architectural plan/drawing of the installation/instrument).



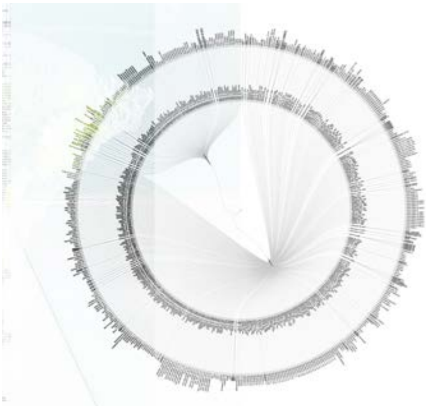


Figure 8 a. Military Satellites; concentric clusters organised according to the main criteria of the "Possibility of Being Tracked": Source: https://www.n2yo.com/satellites/ ; Diagram Algorithm: RAWgraphs, https://rawgraphs.io/ , https://app.rawgraphs.io/; Diagram Category: Circular Dendrogram; Data Hierarchy (from the inner to the outer ring): Possibility of Being Tracked - Launching Site – Name of the Object. Data editing, analysis, and postproduction: Dragana Ćirić;
b. 890 UN Unregistered "cosmic objects"; Source: UN Office for Outer Space Affairs http://www.unoosa.org/oosa/osoindex/search-ng.jspx?lf_id=; Diagram Algorithm: RAWgraphs, https://rawgraphs.io/ , https://app.rawgraphs.io/; Diagram Category: Circular Dendrogram; Data Hierarchy (from the inner to the outer ring): State/Organisation – Launching Date – Name of the Object. Data editing, analysis, and postproduction: Dragana Ćirić;
c. Geostationary Satellites; concentric clusters organised according to the main criteria of the "Possibility of Being Tracked" (the vertical red line marks the only registered satellite whose tracking is not possible): Source: https://www.n2yo.com/satellites/ ; Diagram Algorithm: RAWgraphs, https://rawgraphs.io/ , https://app.rawgraphs.io/; Diagram Category: Circular Dendrogram; Data Hierarchy (from the inner to the outer ring): Possibility of Being Tracked - Launching Date – Name of the Object. Data editing, analysis, and postproduction: Dragana Ćirić;
d. Space & Earth Science Satellites; concentric clusters organised according to the main criteria of the "Possibility of Being Tracked" (two main groups are distinguished in the central area): Source: https://www.n2yo.com/satellites/ ; Diagram Algorithm: RAWgraphs, https://rawgraphs.io/ , https://app.rawgraphs.io/; Diagram Category: Circular Dendrogram; Data Hierarchy (from the inner to the outer ring): Possibility of Being Tracked - Launching Date – Name of the Object. Data editing, analysis, and postproduction: Dragana Ćirić.

2.2 Systemic Thinking and Design: Components of the *Responsive Architectural Dynamic System*

The *Exo* architectural object and system contain several components. They integrate (1) sentient unit, (2) command-and-control, or electronic and digital unit (referring to both hard and soft elements), (3) motor or actuation unit, and (4) kinetic unit, all within the proposed spatial geometry and structure (Figure 9). Each component and system as a whole provide important operational and physical attributes that make this class of spatial objects recognisable and capable for assigned research and display performance, while they also qualify certain spatial objects or entities for *architectural responsive systems*, *programmable architecture,* and *architecture-instruments* designation. According to still unpublished material which will deal with a more detailed explanation of all the attributes of this type of system, object, or architecture [19], the main attributes comprise 01. sentience, 02. algorithmic control and automation, (including 02a. the possibility of autonomy based on *smartness* and *intelligence*, 03. kinetics and performativity, and 04. interactivity and responsiveness. This discussion will put the focus on the instrument's soft component (or attributes under the numbers 2) – the logic of the instrument's performance. The set of procedures, explained through the instrument's plan of operation in regard to each systemic component and their parallel and complementary functions, has been devised to follow several modes of operation, or protocols [20] as basic instructions for information processing and execution of thereby algorithmically transcribed operations.

The prototyping methodology, based on the iterative design process, a greater number of tests, versioning and variation, and improvements according to the assessment of the instrument's performance during each phase of development, has allowed that the systemic components remain unevenly represented during specific phases. The current stage of development has left the algorithmic networking and relationality between the operation of the sentient unit, the input data from digital databases and tracking software, and instrument's kinetics partly unresolved, and this has been the main reason for choosing the algorithmic performance for the main subject of interest in the following section of the paper. The next development phase will put emphasis on the algorithmic code for full systemic integration according to three different programmes the instrument should be able to perform [7] (p. 29). The command-and-control protocols and their brain-like activity, as well the possibilities of their intelligent (autonomous) modes of performance, had to be separately investigated in terms of both the theoretical background and practical, technical needs for their design and integration. The outline has been completely defined prior to execution of the first prototype [7] (pp.27-29), while the theoretical observations will be presented in the following section as a speculative precondition to the next stage of the algorithmic integration and technical solution development in regard to this systemic register and unit.

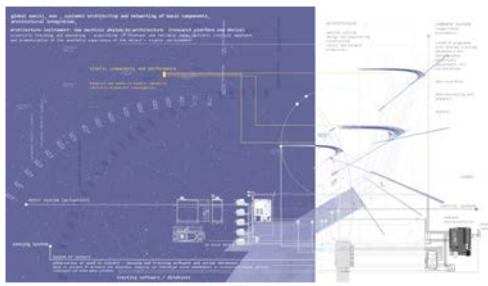


Figure 9 Exo [global eye(s) pilot project: diagram of systemic integration and system design analysis; decomposition regarding incorporated sensing system, motor system, command-and-control system (algorithmic integration), and the system of kinetic components, all within the proposed architectural setting, geometry and configuration.

Systemic architectural integration makes an important statement in regard to the interdisciplinary connections and skills that have to be mastered. It straightforwardly argues the position of the architect-programmer and multifaceted engineer, or at least the professional capable of assembling correct and unambiguous instructions, action plans, and strategies for developers with expertise in fields adjacent to the architectural area of competence and specifically involved in these kinds of projects. (More on the issues of systemic architecture - [21])

3. Soft Architecture of the *Exo-System*

The following section will completely cite the part of the unpublished research material organised through the form of the scientific paper *Exo Case-Study and Prototype of the Dynamic Architectural Responsive System: The Key Attributes of Systemic Integration and Design* [19]. It refers to the chapter that deals with issues of (a) algorithmic control and automation, and (b) system autonomy based on *smartness* and *intelligence*.

3.1 Algorithmic Command-and-Control and Architecture

This section of the paper deals with “soft” components of the *architecture-machine/instrument*. It raises the awareness of the importance of software and programming aspects that such architecture might be embedded into, equipped and paired with if not completely being of a *soft-type* itself (i.e., *architecture-system* or *architecture-information*). Control systems with their performance instructions and communication infrastructures that enable networking of different sources and data-transmission, represent important aspects of the analysis and part of the *architecture-instrument*'s concept and design. The plans require both “hard” spatial setting and configuration, and the “soft” logic of its operation, designed in accordance with each “hard” element of the system and the system as a whole. The rigour and reliability of this *software*'s processing (which in this case has an extended coverage referring to the integration of sentient, information, and cognitive processing alongside control of the kinetic operations) shape the precision of the output data. The fact that the task of the software design has to be either performed or completely specified and supervised by an architect, demands from him the additional skills, knowledge, and disciplinary collaborations.

3.1.1. Algorithmic System of Architecture: Command-and-Control Integration and Cybernetic Degrees of Openness

Aside from the material units of the system, the algorithmic component is completely abstract, open and most easily transformed according to the research plan, tactics, methodologies, and objectives. It is the only one that can completely respond to and enforce the attributes of constant reconfiguration and plasticity in the way that the cognitive abilities and information processing evolve towards the higher information forms in living systems or organisms, going even beyond their capacities in certain aspects. Algorithms and algorithmic integration also imply the highest potential for the change of the level of control and openness of the system they pervade while networking all the components and making them work in a concerted and interactive way through the very course of the object’s operation. Thus, if one refers to the specification of the algorithmically integrated and controlled systems according to the main systemic criteria for systems categorisation ((1) the character of the change - open/closed; (2) the relation with the environment - open/closed; (3) the objectives – fixed/variable; and (4) the implementation of the feedback loop – strong/loose inner control), the programmable nature of the algorithms can make them: fully ***open*** (1) (both considering the character of their change and relation to the environment since other (tracked) systems and processed information influence their operation, and primary processing tasks), highly ***dependent*** (2) on received and registered data (dependent on other systems they interact with) but ***modelled to retain the inner control*** (3), while the ***objectives*** (4) ***could be both fixed (preprogrammed) and variable (constantly reprogrammed)***. The algorithmic control is, therefore, the main aspect that orients the system to pertain to a particular systemic class – namely dynamic and cybernetic – while the ***programmable system*** [22] (p.1227) with the highest degree of openness could be added to these types as well. The *programmability* ("the ability to govern a large class of processes in some uniform way" [22] (p.1226) alongside the implication of computation and recomputation of instantiated physical systems [22] (p.1227)), makes the system address new missions, change parameters, be capable of improving its operation through performance tracking, assessment and learning processes, and cumulatively approach the state of the higher degree of autonomy. Thus, besides the openness, the particular type of the algorithm and the controlling software determine also a degree of the system's *autonomy* - independence in decision-making regarding human control or supervision. This feature is also recommended to be precisely outlined as an important operational aspect in the very conceptual phase: an *embedded (interactive) algorithmic system* that resides within the architecture and enables it to be pervaded by information flows, becomes the subject of delicate design and attribution as well. Its importance, besides the command-and-control performance and the automated problem-solving, lies in the fact that it will determine the main abilities and characteristics of the synthetic architectural whole by enforcing the assembly and reassembly (both physical and computational) of its diverse components, its activity in time and the planned reconfiguration in terms of the logic of components networking (changing the connections among the components), data flows and processing (changing the procedures and functions) and spatial geometries (changing the components physical dispositions).

Considering the embeddedness and the nature of the software (computing) systems and their relation to spaces/environment and humans, Kitchin and Dodge recognize several different forms of computing (algorithmic or software control and guidance of the performing processes) – *pervasive*, *ubiquitous*, *sentient*, *tangible* and *wearable* [23]

(p. 216) (partly [24] (pp.36-37)). As a consequence of their utilization, the resulting spaces might be classified as *coded spaces* (*coded objects*, *infrastructures*, *processes,* and *assemblages*) and *code/spaces* (spaces pervaded with wireless signals and infrastructures, with codes for their control and communication, monitoring, navigation, environmental close-up and remote sensing, etc.). *Coded spaces* and *code/spaces* can be contended "… where the transduction of space is mediated by or is dependent on software" [23] (p.73), considering the transduction to be "a kind of operation in which a particular domain undergoes a certain kind of ontogenetic modulation" [25] (p.10), [23] (p. 72) through which *in-formation* and *individuation*, or a "constant making anew of a domain in reiterative and transformative practices", occurs [23] (p. 263). The code transforms the nature of objects, infrastructures, processes, and finally assemblages, it transduces space (transfers it from one state to another), transforms modes of governmentality and governance, and engenders new forms of creativity and empowerment [23] (p. 20). It incites a dynamic behavior and change in affected entities. Kitchin's and Dodge's terminology helps one to understand the category of space one creates while using software either for its production, control, and functioning, or as an assistive or constitutive component. Since a difference between the *code/space* and *coded space* lies in the power of the software, architectural designs and concepts could be evaluated by this criterion. In the first case, there is a complete dependency of space on software's performance and here, it has been stated, software "literally conditions our [or space's/architecture's, ad. auth.] existence" (here Thrift's and French's explanation of the software's impact [26] (p.312) has been assigned to the first class of spaces – the *code/space* [23] (p.18)) while in the second (*coded spaces*), the code has the role of augmentation, facilitation, and monitoring rather than the complete control and regulation of space as in the previous case. Whether spaces and architectures are totally determined by the code and the software (meaning that its functioning could be completely imperiled by the software's failure), or able to function even after this happens (with possibly undermined efficiency but still independent and operational to a certain degree), represents an important feature for their correct denomination.

From the first cybernetic approaches to architectural design, it becomes evident that concepts based on software operation and command-and-control instructions regarding a designed performance, lose meaning or cease to exist without the algorithmic integration. Thus, the relevance of coding is measured not just by a degree of space/architecture augmentation, but by a degree of inherence to space or architecture, becoming its inseparable component and register. The inquiry of this last degree of integration characteristic for the *code/space* class of spaces has been in particular the objective of this research. The control unit and the code for the *architecture-instrument*'s performance are essential for its functioning and the initial concept. They control the processing of the acquired and measured data, the sensory system, the work of the motor engines, and transposition and conversion of the scientific information into the kinetic performance and effects, all according to the predefined design scenario. Without the instructions for their operation, the most important formative attributes would be refuted (cybernetic approach, kinetics and movement, data processing, etc.), discrediting thereby its responsive, kinetic, cybernetic status claimed in the first place, as well as the convergence and integration of the mechanical, architectural, electronic and software design. The instrument would be an inanimate static sculpture - the empty form without its active performative function, cognitive abilities and responses emerged in relation to the environmental conditions. Therefore, in *Exo* case-study, the relationship between *the space and the code is mutually constituted* [23] (p.18) or *produced through one another* [23] (p. 261) – the spatial concept and kinetic choreography rely on the algorithmic instructions and their input information processing (the code is written according to the prescribed logic, scenario, scientific objectives and methodology) and they are the result of its proper performance, while simultaneously its openness for self-improvement and programmatic change can influence the starting hypothesis or a condition in scientific and artistic research.

The three options of data acquisition that *Exo-instrument* proposes are related to different types of computing. The experiment can deploy aspects of either *pervasive*, *ubiquitous,* or *sentient computing*, and eventually certain kinds of their combination within the comparative and convergent data-analysis method. In the first case in which the instrument's performance and measuring are based on its internal sensory system, the applied mode of computing is *sentient*; the instrument's sentient system registers parameters present in the closer and more distanced environment (depending on the targeted class of objects or specific individual objects), directly having the first-hand information about their presence, activity, location and the impact of the received signals. In this form, the instrument can also become a specific computing device able to potentially become a more active part of the digital system if plugged into its network. The second systemic option which includes existing databases and thereby provided and presented information for the analysis and conversion into kinetic performance, integrates internet infrastructure and exchange of information; in this case, the instrument itself becomes the environment coupled with the already existing wireless systems and information exchange in the air and atmosphere, qualifying for the *pervasive computing* designation. This option can also integrate all the existing devices within the network targeting their ability to perform as external sensing tools – the units of *ubiquitous computing* moving around with their carriers (including both close-up and remote sensing); the instrument's software converges thereby acquired data towards its investigative objectives. The third option relies upon the specialised software for satellite tracking which has been installed on the instrument's computing system and grounds its analysis on the data that this tracking system provides and processes.

Based on everything being said, the computing designation of the (*Exo*) architectural object, system, or environment depends on the mode of data-acquisition that the instrument uses while working in a scientific regime and with reliable information. When applied as a closed performative testing object which operates solely within the artistic and architectural registers (under their kinetic and constructive working regime whose main objective is to test static and dynamic architectural properties and forces), the instrument might use the *algorithmic simulation* and just basic, simple codes for kinetic performance. Hereby, it will only test the functioning of the mobile components, the systemic networking, and relations between all units, as well as prove the system's concept of technical integration as structurally tenable so that all other parts could work properly when finally put into the operation under the scientific comprehensive sensing working regime.

3.1.2. Internal Algorithmic Automation: The Invisible Processing

As it has been explained, the complete integration is algorithmically mediated. The notion that the control of the system and the tasks this system performs "take place within the system, the computing and the output components…" [27] (p.109) apply to *Exo*'s performance, too. The movement and responsiveness are governed by the protocols which can be changed by the designer's decision and administration, all according to the defined tracking programme and the information that needs to be extracted, processed, and analysed from the environment. This inner reconfigurability (the ability to change code "connections", or computing and recomputing of data structure) that enables the performance to address different issues, is paired with physical reconfiguration (possibly even *radical reconfiguration* [22] (p.1226)): it results in a physical rearrangement (as an effect of the relation between data restructuring and physical restructuring of an entity in question, [22] (p.1228) or in other words, the altering of the *hardware* (the architectural components and their networked geometry). In the simulation mode, the mode that has been assigned to the first prototyping phase, design relied upon the Arduino code library by using either standard codes in their initial state that were available as such (e.g., control of servo motors) or upgrading and adapting them according to the performance task (e.g., definition of the precise position of the kinetic components). And while the first prototype has been testing the dynamic properties and structural resistance of the designed architecture during its operation (its "innervated" physical properties) which justified the simulation mode and simple coding performance, the final prototype will include a more delicate approach to programming and software integration, especially for the case that simultaneously uses all three modes of data-acquisition and provides active signal response directed towards the environment.

An algorithm is a formal statement that describes a procedure necessary to perform a defined task. In computer systems, algorithms define recursive procedures which are implemented in a code that makes it possible to execute the defined procedures in a given hardware and software environment. [27] (p.108)

As *chains of translating calculations*, algorithmic operations steer further performance of the technical/mechanical device or its components (in reference to Broeckmann's notions, [27] (p.90) – they control and shape the *machine*'s action (the execution of the given protocols). By translating initial signals or collected information into operative data, analysing and processing them so as they can become the control signals that drive the output units (motors, kinetic modules, or response modules), algorithmic formulas fully enable a designed performance. They provide and "dramatise" sensible experience. Still, algorithms stay imperceptible and inaccessible to the observers in forms other than what they see it's happening - "what the algorithm actually does" according to the methodology and the scenario. The codes stay fully available only to a scientist-designer and/or its professional technical support.

… the working of algorithms and their processing of symbolic values cannot be observed directly by the human senses, but can only be experienced through their effects in the connected devices. The fundamental obscurity of this "machine" and its automatisms are a key feature of the aesthetics of computer-based art. [27] (p.90)

When speaking about the inscrutability of an algorithm, the conclusion about its performance comes through "whatever the [artistic, emphasis added] work "does": its existence has been "inferred from what is happening" [27] (p.119) and visible performance (the output information) is regarded as an agency of the algorithmic presence and operation. Therefore, the famous discourse of the inaccessibility and obscureness of the algorithm can be applied again. Although digital literacy has become widespread, the code's performance is still "embedded into objects and systems in subtle and opaque ways", performing in manners "that are not clear and visible" from the outside and producing "complex outcomes that are not easily accounted for by people" [23] (p. 5). Its designation of "technological unconsciousness" or "sublime" implies the highest cryptic level. From a designer's point of view, the idea of defining properties of this "unconscious" behaviour is more creatively daring and demanding than any other clearly and unambiguously defined AI. While seeking to establish the relationship between the design of an object/architecture and the design of a software, the basic scenario of executive tasks is not so hard to define if following research methodologies and objectives, additionally supplementing them with performative "dramatization". What comes as more challenging is the inclusion of *intelligence* and *autonomy* on certain levels of such algorithmic performance.

Considering the question of more complex and intelligent work of the used algorithms, *Exo* defines a plan for their further development, but at this moment stops with the basic enablers of defined performances. The system's *smartness* (the performance awareness), *machine learning* and *intelligence* (independent decision-making, problem-solving, and self-improvement as higher cognitive abilities) will be the major subjects of the next research and prototyping phases.

One of the tasks and objectives of an instrument has been to reveal internal processes of tracking and analysis of the invisible parameters. It aimed at making them more intelligible and comprehensible in an aesthetically immersive and appealing way. A didactic potential of the *instrument* for engaging new solutions of certain components and their upgrading has been followed by the attempt to make their investigative procedures, tests, final installation and assembly visible, thus also easier for scientific supervision. The algorithmic process is however still intangible and inaccessible to external parties in this regard, but the displayed work and a structure imply its procedural logic, while the code's very representation (or the question of whether it should be accessible in a literal way) could be one of the next assignments in the course of the research.

3.1.3. Algorithmic Architecture

Algorithms can be seen as *machines* on their own – either "individual" machines or the ones operating inside another machinic (or spatial) system. They are responsible for behaviour, performance, operation, and information processing of the whole entity. Since not being directly perceptible and material, they, in a way, obscure the relationship between the cause (the input information) and the effect, the outcome, or performance (the output information). An insight into the ways by which its logic steers all the processes remains inscrutable.

The *Exo*'s overall technical operations simultaneously involve algorithmic, electronic, and mechanical design, all embedded within the central design of the architectural structure and a system. While *algorithmic architecture* could imply both the architecture of the written instructions for the *instrument*'s, *machine*'s or other entity's performance, and the architecture that embeds the code or is embedded within the *coded infrastructures*, in the case of this particular prototype the first comes as a precondition for the full operation of the second, including mentioned electronic and mechanical components, and structural details. The algorithm is a virtual engine that animates the structure, enables its investigative tasks to be enforced and performed, and incites a basic *smart* or *intelligent response*.

Aware of the difference between mechanical and algorithmic automation [27] (p.108), one can more informatively speculate about the format one uses in prototyping and experimentation. Methodologically derived from the decisions about the system's operation and governing, the questions of *interactivity* and *autonomy* explained in the following sections, will add further information to more precise specifications of that particular format.

3.2. Autonomy - Smartness and/or Intelligence

Algorithmic control and the effects of the object's performance are specified by the property of *autonomy* based on a degree of algorithmic *smartness* and/or *intelligence*. 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 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 unpredictable sets of information. The part of the experience of *machinic autonomy* (*autonomous machine aesthetics*) is manifested by the awareness of the inability to intervene in the machine's operating tasks and its performances (using herewith Broeckman's notions on similar issues in machine art practices, [27] (pp.107-108)). This would be one side of the interpretation or mediated experience of the algorithm's working. 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 the type of algorithm used for the machine's operation, comes to the fore while delving into 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 [23] (p. 99). While *smartness* provides the ways to track objects' performances 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 even develop the initial code by itself. These last cases may be compared to the *seed AI* [28] (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 [28] (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” [28] (p.34) achieving constant “recursive self-improvement” [28] (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 behaviours 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* [23] (pp.217-218), but in both cases, it provides a higher degree of object’s *autonomy* and unpredictability in interaction with humans and the 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” [28] (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 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, [29] (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) [12] (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) [26] (pp. 320-323)) for the machine’s cognitive performance and self-enhancement. These algorithms are the main conditions for the machine-learning abilities, enabling thus presumed machinic self-improvement, transformation, recreation, and eventually completely autonomous behaviour and decision making. Architectural system/machine that performs and changes in this way 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, John and Julia Frazer [30], Negroponte's *room-machine* [30] or its contemporary counterparts such as *Ada: the intelligent room project* [31] (pp.86-89)), as well as in some more recent concepts of *smart* and *intelligent cities* and *environments* [32, 33], [23] (p.99, pp.217-218), *code/spaces* and *coded spaces* [23], and different examples of direct applications of generative and evolutionary techniques in art and architectural design (e.g. [34]). 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* [28] (pp.3-4). The *autonomy* in some of the cognitive fields 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 already mentioned ability to engineer their own structure, perform self-enhancement with data, 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 capabilities – *superintelligence* ("any intellect that greatly exceeds the cognitive performance of humans in virtually all domains of interest"; [28] (p.26)).

The abilities and designations of the architecturally incorporated, integrated, or engaged computer networks and algorithms, alongside the type of the 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 some of the later stages (contained in and defined by the proposed and constructed scientific and artistic research and prototyping methodologies).

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

Since the installation (or an instrument) does rethink the biological counterparts of its machinic design solution [7] (pp.25-26), being aware that the sentience, data processing, and motoric reaction have been expressed as highly discrete or systemically fragmented operations, the question of the smooth continuous performance of a kind of *integrated intelligence* and the relation between the biological and machine procedures, do appear as relevant topics for a discussion. Having "presence as 'local intelligence'" ... "somewhere between the artificial and new kind of natural..." as Thrift and French would argue [23] (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 the software as "not [being] sentient and conscious while exhibiting characteristics of being alive" [23] (p.5), through different types of machine learning algorithms (deep learning algorithms and neural networks [28] (p.6, pp.9-10)) that make them closer to biological systems (generative (adversarial) networks, convolutional networks, evolution-based algorithms such as genetic algorithms, etc.), and finally complex multisensory integration and processing (with the extremes in predictions of *superintelligence* [28] (p.26) and *technological singularity*), the technoscientific development might revoke initially posed claims of the AI's lagging behind the human intelligence due to still insufficiently satisfying performances in certain aspects (mostly those within the field of sentience and emotion, but these were also significantly advanced in the last couple of decades (e.g. *Affective Computing* [26] (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" [29] (p.9). By adding sentient performance, 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 (*multi-INT*) capabilities into an end-to-end integrated system that will influence the automated collection and actionable response), revolutionise the current sequential tasking, collection, processing, exploitation, and dissemination (*TCPED*) cycle by enhancing it into a learning and adaptive cycle (Sentient R&D program [35]), all through the use of sensing technologies. It may be said that such a prototype could be the ultimate model for *Exo*'s and other similar objects' performances.

The software is also responsible for the possibility of active interplay in architectural settings. It animates static object-forms and systems – informs with a special kind of life a non-livable matter and thus enables architects to conceptualize, design, and produce active dynamic forms. Therefore, it represents the convenient means and the formula for the realization of the next two sets of design objectives and attributes – *kinetics* and *performativity*, and *interaction* and *responsiveness*.

4. Conclusion

In concluding remarks, it is important to disclose the difficulty of representing only one aspect of complex systemic solutions or projects and get a complete grasp of all the topics that have been involved and all of its contributions. The study should also be read through the texts already published on the topic and through all the references as a perfect netting for the more focused investigations. The fact that artistic and scientific methodologies could, by choice, exist and produce in a combined manner better research results, both of them controlling, articulating and refining the setbacks of the other and enhancing the experience of mediation and use of the constructed objects, does make an important starting position for similar efforts in future design research practices, and the precise explanations certainly adjoin the existing design research and strategic epistemology. New architectural integrations, forms, and collaborative frameworks provide more opportunities to investigate and learn about architectural design and extend its boundaries, while at the same time executing the fully functional prototypes or architectural space.

The software integration in architectural or spatial design makes one more important universal research subject that the project has widely explored. The ideas of intelligent architectural performance or intelligent environments have come to the point of almost being a standard in architectural theory, critique, and even practice, and as such, they demand complete mastering alongside critical perspectives on their prospects and future progress. The modes of algorithmic integration, control, and articulation of architectural performative and interactive features or actions, as they have been conceived to operate in the case of the *Exo* project, provide a good example of the possible application within the argued artistic-scientific convergence. In such context, the architecture might easily become an intelligent or thinking instrument or device that protects the life within its boundaries on one more level – not just material, but also immaterial and invisible one, regulating the entry of various environmental and artificial signals and information to the interior spaces it defines. The algorithmic instructions that determine this architectural intelligence and behaviour are the same ones that imply the aesthetic components of the architectural structure and system. The logic they follow and apply represents the key scenario of the architectural performance, and it has been proved that this scenario can have several modes – it can follow either scientific methodology while aiming to deliver the best spatial conditions (in regard to the parameters it articulates) and provide a desired environmental information (whether these parameters are of a natural or artificial origin), or it can create the sensory and aesthetic effect according to other user-requirements (all including senses and their either enhancement or distraction in both positive and negative ways).

The internal algorithmic logic, finally might recognise certain patterns and regularity and even impose such modes of operation in order to simplify the systemic demands or try to deal with unpredictable, non-linear, or complex designs which are the major challenges regarding this register of the Exo prototype. Thus, the most intricate forms that could animate architectural spaces will close this study, tracing a direction of future investigations and advancements regarding questions of the project's further development.

References

[1] Buckler, J. A. (2004). Towards a New Model for General Education at Harvard College.

[2] Müller, K. H. (2014). Mapping a New

and Post-Disciplinary Research Frontier: Science and Cybernetics at the Second-Order Level. In *The New Science of Cybernetics. Volume 4: An Interim Report, "Second-Order Science" Special Issue of Constructivist Foundations*

[3] During, S. (2011). Postdisciplinarity. (A talk given at the Humanities Research Centre at the ANU. (May 2011), URL: https://www.academia.edu/764233/Postdisciplinarity

[4] Petts, J., Owens, S., Bulkeley, H. (2008). "Crossing boundaries: Interdisciplinarity in the context of urban environments." *Geoforum*, 39 (2): 593-601.

[5] Linder, M. (2004). Nothing Less than Literal: Architecture After Minimalism. Cambridge, Mass.: The MIT Press.

[6] Ćirić, D. (2017). *Scripts and Codes of Architectural Design Process: Disciplinary Borders and Transfers (Doctoral Dissertation)*. Belgrade: Belgrade University - Faculty of Architecture, July 2017.

[7] Ćirić, D. (2020). Exo [global eye(s)]: Dynamic Responsive System (Critical Review of the Research Project, Prototype and Exhibition Concepts). *Architecture and Urbanism*, 50, 20-35.

[8] Ćirić, D. (2020). *Architecture-Instrument*: The *Architecture-Machine* Origins and Frameworks of *Machinic Line of Thinking in Architecture*. In Đukić, A., Krstić-Furundžić, A., Vaništa Lazarević, E. and Vukmirović, M. (Eds.), *7th International Academic Conference on Places and Technologies 2020 – Proceedings: Keeping up with Technologies to Act Responsively in Urban Environment*. Belgrade: University of Belgrade – Faculty of Architecture, Vol. 7, Ch. 54, 450-466. doi: 10.18485/arh_pt.2020.7.ch54.

[9] Raskusin, B. (1977). The Architectural Theory of Luca Pacioli: De Divina Proportione, Chapter 54, *Bibliothèque d'Humanisme et Renaissance, T. 39*, 3, 479—502, http://www.jstor.org/stable/20675777

[10] Da Vinci, L. (1906). *Leonardo Da Vinci's Note-Books*, (Arranged and rendered into English with Introduction by E. McCurdy) London: Duckworth & co., New York: Charles Scribner's Sons.

[11] Findlen, P. (2013). Agostino Scilla: A Baroque Painter in Pursuit of Science. In *Science in the Age of Baroque*, Gal, O., Chen-Morris, R., Eds (pp. 119-160). Springer: New York and London.

[12] Wihart, M. (2015). *The Architecture of Soft Machines* (Thesis submitted to The Bartlett School of Architecture, University College London, in fulfilment of the requirements for the degree of Doctor of Philosophy (Ph.D. Architectural Design). London: Bartlett School of Architecture UCL.

[13] Menking, W. (2016). The Museum of Applied Art delves into the ambitious, diverse career of Friedrich Kiesler. *The Architect's Newspaper*, July 8, 2016. Accessed December 15, 2019. https://archpaper.com/2016/07/friedrich-kiesler-life-visions-mak/#gallery-0-slide-0

[14] Dunne, A. and Ruby, F. (2013) *Speculative Everything: Design, Fiction and Social Dreaming*. Cambridge, Mass.: The MIT Press.

[15] Nay, E. (2013). Problematising New Technologies through Design. *International Journal of Humanities and Social Science*, 3 (5): 108-114.

[16] Cash, P., Stanković, T., Štorga, M. (Eds.). (2016). *Experimental Design Research: Approaches, Perspectives, Applications*. Springer.

[17] Cash, P., Stanković, T., Štorga, M. (2016). An Introduction to Experimental Design Research. In Cash, P., Stanković, T., Štorga, M. (Eds.). *Experimental Design Research: Approaches, Perspectives, Applications*. (pp. 3-12). Springer. https://doi.org/10.1007/978-3-319-33781-4_1

[18] Ćirić, D. (2019). [18Hz] Personal remote/close-up sensing instruments and architecturally integrated networks. Abstract and scenario written for the *Future Architecture Fair* Exhibition and pitch presentation, MAO, Ljubljana, 13-15 February 2019.

[19] Ćirić, D. (2021). Exo Case-Study and Prototype of the Dynamic Architectural Responsive System: The Key Attributes of Systemic Integration and Design (unpublished material – draft paper)

[20] Galloway, A. R. (2004). *Protocol: How Control Exxists After Decentralisation*. Cambridge Mass.: The MIT Press.

[21] Ćirić, D. (2020). System Architect: Digital Literacy and Construction of the Digital and Object-Like Environments for Research Operations. In Bogdanović, R., Ed. *Eight International Conference 'On Architecture' "Learning Architecture" Proceedings.* (pp. 49-63); STRAND: Belgrade.

[22] MacLennan, B. J. (2015). The Morphogenetic Path to Programmable Matter. *Proceedings of the IEEE 2015*, 103(7):1226–1232. doi: 10.1109/JPROC.2015.2425394.

[23] Kitchin, R. and Dodge, M. (2011). *Code/Space*. Cambridge, Mass.: The MIT Press.

[24] Jaskiewicz, T. (2013). *Towards a Methodology for Complex Adaptive Interactive Architecture*. Ph.D. Dissertation, Technische Universiteit Delft.

[25] Mackenzie, A. (2013). Transduction: Invention. Innovation and Collective Life. Unpublished manuscript,. Available online: www.lancs.ac.uk/staff/mackenza/papers/transduction.pdf.

[26] Thrift, N. and French, F. (2002). The automatic production of space. *Transactions of the Institute of British Geographers*, 27(3): 309 – 335.

[27] Broeckmann, A. (2016). *Machine Art in the Twentieth Century*. Cambridge, Mass.: The MIT Press.

[28] Bostrom, N. (2014). *Superintelligence: Paths, Dangers, Strategies*. New York: Oxford University Press.

[29] Gomez-Luque, M. and Jafari, G. (2017). Posthuman. In Gomez-Luque, M. and Jafari, G. (Eds.). *New Geographies 09: Posthuman*. (pp. 8-11) New York: Harvard University Press.

[30] Wright Steenson, M. (2017). *Architectural Intelligence: How Designers and Architects Created a Digital Landscape*. Cambridge, Mass.: The MIT Press.

[31] Bullivant, L. Ed. (2005). *4dspace: Interactive Architecture (AD Profile 173)*. 75 (1).

[32] Townsand, A. M. (2013). Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia. New York: W. W. Norton & Company.

[33] Picon, A. (Ed.) (2015). *Smart Cities: A Spatialised Intelligence (Architectural Design Primer)*. London: Wiley.

[34] Frazer, J. H., Frazer, J. M., Liu, X., Tang, M. X., and Janssen, P. (2002) Generative and Evolutionary Techniques for Building Envelope Design. In Soddu, C. (Ed.), *Generative Art 2002, 5th International Generative Art Conference GA2002 (Proceedings)*, (pp. 11-13.), Milan, 11-12-13 December 2002. Milan: Generative Design Lab, Department of Architecture and Planning Politechnico di Milano.

[35] *(U)Sentient, NRO Key Talking points/2016*, Approved for Release: 2019/02/19 C05112983. Available online: https://www.theverge.com/2019/7/31/20746926/sentient-national-reconnaissance-office-spy-satellites-artificial-intelligence-ai, https://www.nro.gov/Portals/65/documents/foia/declass/ForAll/051719/F-2018-00108_C05113708.pdf, https://www.nro.gov/Portals/65/documents/foia/declass/ForAll/051719/F-2018-00108_C05112980.pdf