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# Sound Shape Space
## Architectural Representation of Soundscapes with the use of Artificial Neural Networks

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*i. Abstract*

*This doctoral thesis proposes a new strategy for evolving architectural structures based on the idea of adaptation to a dynamically changing environment, with the use of advanced machine learning and AI methods. The evolving architecture uses physical and cognitive processes that are transformed and assembled into structures based on environmental properties and capabilities. The project investigates a living dynamic system as a complex set of natural and cultural sub-processes in which each of the interacting entities and systems creates complex aggregates. It deals with natural processes, communication flows, information networks, resource distribution, dense noise masses, a large group of agents and their spatial interactions in the environment. By significantly expanding existing research, the project creates a meta-learning model useful for testing various aspects of adaptation to a complex dynamic environment. This refers to the difficulty of designing artificial agents that can intelligently respond to evolving complex processes.*

*This multidisciplinary project transfer knowledge into the field of architectural creation, from cognitive neuroscience and human-computer interaction approaching digital modelling through machine learning algorithms. The theoretical part of the thesis outline novel approaches to grasp space, material and architecture in a models of waves and particles. It contains a study of digital sound-spatial structures - soundscapes. The project is a case study of the implementation of new approaches in architecture that are a cutting edge of the contemporary computing technologies. It investigate applicability of machine learning algorithms in the context of spatial dynamic forces, as a tool for architectural representation of sound and dynamic spatial structures. The second part of the thesis deals with the application of more complex machine learning models for Architectural Intelligence.*

*The experimental part focuses on the concept of a dynamic environment. Then the concept of evolutionary architecture and Architectural Intelligence is introduced based on the ideas of adaptation to environmental changes. The common machine learning algorithms and neural networks have a limited range as they deal with individual tasks and are not sufficient for modelling complex adaptation processes. Therefore, the thesis propose an approach based on advanced methods such as meta-learning, in which the knowledge gained to solve one*

*task can be generalised and applied to many other tasks. It presents the applications of meta-learning to analyse and design architecture and tests the proposed theoretical framework of Meta-Evolver in the form of an immersive digital environment.*

*ii. Key Words*

*adaptation algorithms architecture architectural intelligence artificial intelligence brain cognitive complex systems data digital design dynamic environment evolving forms general human computer interaction information processing machine learning methods music neural networks patterns representation sound space spatial structures systems technology virtual*

*iii. Abstrakt (česky)*

*Tato disertační práce navrhuje novou strategii evolučních architektonických struktur založenou na myšlence adaptace na dynamicky se měnící prostředí s využitím pokročilých metod strojového učení a AI. Evoluční architektura využívá fyzické a kognitivní procesy, které jsou transformovány a sestavovány do struktur na základě vlastností a schopností prostředí. Projekt zkoumá živý dynamický systém jako komplexní soubor přírodních a kulturních dílčích procesů, ve kterých každá z interagujících entit a systémů vytváří komplexní agregáty. Zabývá se přírodními procesy, komunikačními toky, informačními sítěmi, distribucí zdrojů, hustými šumovými masami, velkou skupinou činitelů a jejich prostorovými interakcemi v prostředí. Významným rozšířením stávajícího výzkumu projekt vytváří meta-learning model vhodný pro testování různých aspektů adaptace na komplexní dynamické prostředí. To se týká obtížnosti navrhování umělých agentů, kteří mohou inteligentně reagovat na vyvíjející se složité procesy.*

*Tento multidisciplinární projekt přenáší znalosti do oblasti architektonické tvorby, od kognitivní neurovědy a interakce člověk-počítač až po digitální modelování pomocí algoritmů strojového učení. Teoretická část práce nastiňuje nové přístupy k uchopení prostoru, materiálu a architektury v modelech vln a částic. Obsahuje studii digitálních zvukově-prostorových struktur - zvukových ploch. Projekt je případovou studií zavádění nových přístupů v architektuře, které jsou špičkou současných výpočetních technologií. Zkoumá použitelnost algoritmů strojového učení v kontextu prostorových dynamických sil jako nástroje pro architektonickou reprezentaci zvukových a dynamických prostorových struktur. Druhá část práce se zabývá aplikací složitějších modelů strojového učení pro architektonickou inteligenci.*

*Experimentální část je zaměřena na koncept dynamického prostředí. Poté je představen koncept evoluční architektury a architektonické inteligence založený na myšlenkách adaptace na změny prostředí. Běžné algoritmy strojového učení a neuronové sítě mají omezený rozsah, protože se zabývají jednotlivými úkoly a nejsou dostatečné pro modelování složitých adaptačních procesů. Proto práce navrhuje přístup založený na pokročilých metodách jako je meta-learning, ve kterém lze poznatky získané řešením jednoho úkolu*

*zobecnit a aplikovat na mnoho dalších úkolů. Představuje aplikace meta-learningu pro analýzu a návrh architektury a testuje navrhovaný teoretický rámec Meta-Evolver ve formě imerzivního digitálního prostředí.*

*iv. Klíčová slova*

*adaptace algoritmy architektura architektonická inteligence umělá inteligence mozek kognitivní komplexní systémy data digitální design dynamické prostředí vyvíjející se formy interakce člověka a počítače zpracování informací metody strojového učení hudba neuronové sítě vzory reprezentace zvuk prostor prostorové struktury systémy technologie virtualita*

## 1. Introduction

**The answer is technology, but what was the question?** asked architect Cedric Price at a lecture of the same name in 1979 - a question that determines the main goal of this work and the basic questions for advanced architectural strategies. With computational thinking, we enter the whole field of novel approaches to an architectural creation and they allow us to define architecture as computational models written in code of successful architectural strategies - **Architectural Intelligence**.

Due to the main aspect of technologies that penetrate not only into our daily lives, much of data science and data analysis come from many different scientific disciplines. This aspect brings the opportunity to work with data across many disciplines and aspects of human activity and transfer knowledge from biopsychology, human behaviour and perception of space to the architectural design. There is an attractive potential for creating creative tools for processing dynamic forces and data fields. This data is treated as material that is transformed into an informed shared space and living responsive environments. The proposed architectural approach represents data, digital information in the entity that embody some form of *Architectural Intelligence*. By observing what defines and influences people's behaviour, perception, and sensory processing, we uncover the basic behavioural configurations that can be found in patterns of communication or information transmission. The human senses process vast clusters of information that reaches them from the outside world as close distant spaces that they represent. These perceptual mechanisms create a large number of layers of reality, and by decoding and exchanging them, we have enclosed them in shared reality. Therefore the model of interlocking forms is proposed, and embraced in the place where space ceased to exist, and only the mutable matter emerge.

The analytical part of the architectural design requires the processing of a large amount of input data. In the experimental part of this work, the noise field, and brain activity are represented by qubit a quantum bit, particles, waves, and dimensions of compositional models in a virtual *controlled environment*. Virtual composition models provide a platform

for testing and assessing the response of emerging environments and situations with respect to the *design theory* and *research hypotheses*. Individual models and prototypes of architectural code, principles and instructions for interaction with the controlled environment, will allow detailed observation and evaluation of all data and take them into account in the entire process of design and learning of *Architectural Intelligence*.

The prerequisite for the creation of *Architectural Intelligence* is the use of advanced computational methods and the application of models for the analysis and representation of large data sources that effectively process a massive volume of data in the form of *architectural intelligence algorithms*. These models can be applied and trained on a micro or macro scale in urban spaces, open landscapes or virtual environments. They allow you to work with all types of data on temperature, humidity, wind force, noise levels, precipitation, information on trends, behaviour, or biological feedback, moods in society and community influenced by human and cultural habits, tendencies and preferences of communities. The data entering the model are sensory or derived from extensive data collections and libraries, data emission atlases, etc.

It outlines the use and verification of these strategies in physical and virtual space, with the application of analog and digital systems and architectures. It defines a novel architectural approach, the *Architectural Intelligence* that will allow to bridge the narrow boundary between the detailed analysis of input information from the environment, and the architectural design.

The design approach encoded within model systems capable of negotiating fundamental architectural problems radically departs from the more simplistic use of *multi-agent systems* for the generation of e*mergent patterns* that act as templates for architecture.

The future architecture design and construction is established on the revitalisation and actualisation needed for every civilised culture to flexibly face the most challenging issues of the recent times.

## Motivation

This work aims to build a computational model of neuro-evolutionary algorithm driven architectures, where space matter particles and neural waves meet waves and particles of sound, and are uniformly revealed in quantum systems of logical structures, flows and fluid compositions.

## Research Problem

This thesis and proposed architectural approach, directs forces and energies, not objects, "not circumscription of a solid but a deliberate polarisation of natural forces towards a specific human purpose."[1] The future of building and architecture are in *multilayered interconnections* between technology, nature and man, and approached with interdisciplinary scientific domains. The architecture always been a multilayered domain and the challenges such as finding the architectural articulation between man and artificial, man and technological or digital environment is an essential quest of future architecture in every aspects.

The research problem is to build a digital platform to visually communicate architectural articulation of relation between human and dynamic environmental conditions and trace behavioural and perceptual balance patterns. This thesis research techniques and proposes a digital tool and creative assistant for architects, a software that provides an insight to the invisible flows of energies, effectively distributed in a meta-space and allows observation of physical qualities that correlate with the human behaviour and perception.

## Research Questions

Digital technologies and communication media have recently been used more and more in all areas of human activity, in digital architecture we are experiencing the same trend and a new challenge for advanced design methods. In the field of architectural creation, adaptation to the technological world is very methodical. New digital tools and new approaches to architectural creation are being accepted with generally great apathy. The transition from tools that have been used for several decades to new tools is facing great difficulties.

In the 21st century, we are experiencing the development of new approaches to analysis, primarily influenced by the possibilities of immediate optimisation of applied and validated knowledge, defining a more accurate and finer boundary between established and validated schemes. These schemes alone are not able to respond dynamically to the ever-changing needs of people, entire communities and the entire ecosystem of the human environment, which adapt to new situations and evolve. Digital architectural creative approaches are dynamically evolving and using their own digital tools and software, thus radically changing the concept of the architectural design process.

The architectural intelligence is a quantum based model that works with meta-material, that consist of qubits, which accurately and efficiently places in a digitally composed architecture. These architectures, are designed with environmental qualities and environmental capabilities in mind, so they perceive and respond together to the complexity of the environment. In the properties of virtual materials, the basic mechanisms are encoded to be able to respond empathetically and instinctively and understand the behaviors and needs of the population or human individual and changes in the environment and effectively unify them into a functional architectural expression.

What does a computer system need to know about the environment and the human user in order to *understand* the human experience?

What computational models are used to process the dynamic forces of the environment, and what are appropriate to integrate into architectural spatial models?

How to build a system of machine learning algorithms that controls the self-balancing

tendency based on behavioural and environmental adaptations?

How to display and visualise trends and directions of *Meta Architecture* organisation?

How does the computer system interfere with the intelligent environment to improve it?

**Main Research Goals**

The main research activities are of the construction and testing of artificial intelligence algorithms (AI), evolutionary algorithms and artificial neural networks (ANN), successful in the classification and clustering of an input data. Secondly testing and examining the outputs of algorithms that find patterns, tame mutations, and support successful evolution.

The research goal is to define an *Architectural Intelligence* based on the multiple dynamic aspects, behavioural and environmental forces, defined as algorithm parameters and instance features.

The negotiated *Architectural Intelligence* in this thesis is based on spatial environmental dynamic force - sound, and its complex spatial compositions - soundscapes of the environment.

The Neuro-Evolution is proposed as a form of Architectural Intelligence that learn, assume and predict behaviour on neural basis from the neuro-bio-feedback, spikes of neurones in a human brain activity reacting on a spatial sound stimuli. The *Architectural Intelligence system* for an complex dynamic environments is based on coded architecture models and multilayered systems.

In order for *Architectural Intelligence* to capture the complexity of the real world, it must include in-depth control and knowledge of large databases of dynamic data. Above all, the architecture should provide new strategies for data collection and processing, the construction of learning models and knowledge transfer, in order to effectively apply what is already known and inform the design to be created.

Algorithmic design is not simply the use of computers to design architecture and objects. Algorithms allow designers to overcome the limitations of traditional CAD software and 3D modellers, reaching a level of complexity and control which is beyond the human manual ability.[2]

## Spatial Representation and Configuration of a Model

Those dynamic physical forces, in a proposed model, that produce a form, are sound waves and noise masses, our body motion trajectories, our brain activity, our behaviour. Brain performance is recognised as a unique sequence of dominate waves that evolve over time. With these dynamic data fields and their features, computational model work as a with a virtual material. The architectural neuro-evolution algorithm is able to evaluate the optimal configuration for a given situation and environment. The dynamic data fields entering the algorithm, are processed and features and parameters are extracted for the chosen evolutionary strategy. Based on these functions, features and parameters, the algorithm generates unique architectural articulations of the physical and behavioural force fields.

## Design Hypothesis

To capture and integrate dynamic power, sound, we need a form of Architectural Intelligence as a set of evolutionary mechanisms that are able to learn and adapt to the dynamic situation of the external environment or changes in human behaviour.

**The Architectural Intelligence is a set of evolutionary mechanisms that has capability to adapt architectural organism to the dynamical environmental or behavioural situation.**

The Architectural Intelligence is both adapting, changing and accommodating the dynamic of the environment.

## Scientific Hypothesis

**The Meta-Learning approach along with the Neuro-Evolution algorithms of the large scale neural networks provide effective intelligent model for a continuous adaptation in a dynamic complex environments.**

Architectural Approach

The status of architecture is on search for an architectural language that can communicate the recent technological world and world of information. This thesis propose to approach architectural language that comes along, with code writing, and composing of code scripts that evolves and rewrite its own concepts and protocols - coded *Neuro-Evolutionary Architecture* algorithms. This architectural approach is suggesting a mathematical language written in a scrips, and dynamic code. The fundamental topological definitions and characteristics of an objects, topological formulas, are developed by a set of evolutionary algorithms and system of trained neural networks that modify a given parameters in to a several super-parameters and adapt them into the balanced organisation.

This research is explored through:

- code prototyping
- neural networks composing
- virtual environment modelling and testing
- experimental audio-visual work and installations (interior, exterior)
- human brain computer interaction
- lecturing and workshops
- scientific publications

**Definition of Research Fields**

The work presented in this thesis is the result of intense multidisciplinary research ranging from Neuroscience, Cybernetics and Computer science, Sound Art and Music Technology and Composition, Architecture and Philosophy, synthesised in novel approach in architectural thinking. These domains and their sub-domains are connected in a scientific

field called Cognitive science. Where the main motivation is joining the architecture with human behaviour and perception processes in a dynamic environment. The exploration in these domains, architectural design, cognitive science and human computer interaction, builded on the mathematical models and algorithms of machine learning, revealed only a fragment of the whole field of complex architectural systems, while there are still number of technical and philosophical problems to be discussed and solved before the long time perspective and main goal where the Architectural Intelligence perform inhabitable environments, is achieved.

**Advanced Architecture**

Architecture is the main domain and focused area of application of research outcomes as well as projection of the methods from the above mentioned scientific fields. The goal is the bridge in-between these research fields and establish a novel methods for architectural design and thinking.

*Digital Architecture*

From a historical perspective, the incubation period of a new medium can be quite long. It took many years for people to think of moving a movie camera, versus just letting the actors move in front of it. It took thirty-two years to think of adding sound.

*Intelligent Environments*

The stability and development of a human-made and human-inhabited environment is determined by the degree of investment in theoretical and economic "intelligence" and the emergence of intelligent environments enhanced with architectural intelligence.

The intelligent environments consist of adaptive conditioning determined by the population themselves in a growth-monitoring and or mechanism-activating adaptive logic system. The intelligent environments learn about its resident and generate an attentive situation - shape. The behaviour of the shape is purposeful, and intelligent.

*Architectural Intelligence*

Architectural Intelligence is a set of evolutionary mechanisms that has a capability to adapt the architectural organism to the new environmental situation or behavioural patterns of it's symbionts, in a sort-term or long-term interactions. The Architectural Intelligence is both adapting, changing and accommodating the environmental dynamic and behavioural conventions. The architectural intelligence is taught by its architect.

The intelligence is encoded in a script of a neural networks models that are capable of rewriting existing code protocols, and therefore actively address acute issues of architecture for effective and dynamic adaptability. This architectural approach proposes a theory of architectural adaptive systems. Intelligence can be seen as a form of adaptation in which knowledge is constructed by each individual through two complementary processes of assimilation and adaptation. Adaptation is an evolutionary process as a result of which the body better adapts to a dynamically changing environment. If an organism cannot move or change enough to maintain its long-term viability, it will obviously go extinct.

In this perspective, *Architectural Intelligence* is a set of methods that adapt architecture to the environmental and social changes and instability. Architectural intelligence is a method of solving architectural problems. It propose the use of computer science techniques, in particular deep learning and meta-learning, to represent and analyse complex architectural and urban phenomena and to find and generate optimal spatial forms. Modelling complex natural processes requires computer science and it is no coincidence that the development of computer science has been largely shaped by the construction of computer models to simulate natural processes. Based on the developed models, we generate intelligent architectural structures that provide sustainable environmental conditions for individuals and communities based on their spatial experience and behaviour. Predictions generated from models with the use of neural networks actively solve difficult problems of architecture in order to effectively adapt to dynamic changes in the environment.[3]

***The architecture it self will be computational machine the engine and the material powerful energy producer and transmitter so the demand on space will be significantly reduced.***

***There will be a several different architectural typologies for different form of computation. That computer architecture will be ever-present in a matter surrounding and creating our environment.***

***The computing capacity will be given by the material structuraslization and effectiveness of energy and data transmission.***

## Methodology

This research proposes a framework for advanced architectural design and thinking, based on modulation of the dynamic medium, classification of an extensive multidimensional data base, translated with architectural language into a compact and coherent intelligent environment in code.

*Contextual Purposes*

This work is based on two approaches, firstly on experimental work with multidimensional data collections, in the scope of this research, database of recoded brain responses on various audio stimuli and spectro-spatio-temporal experiences and features. Secondly on the form finding by logical and generative models, machine learning evolutionary algorithms, and generative neural networks. All resulting in Self-Controlled and Self-Replicable Computational Models and Algorithms for Advanced Architecture Design. The experimental work and coding is based on Python language along with TensorFlow and Keras libraries, with extension to advanced computer music audio-visual programming softwares (Processing, Pure Data, SuperCollider). The prototype of generative dynamic environments is developed and tested in various game engines (Unreal Engine, Processing, etc.) and exposed to multidimensional data - generated ambisonic sound signals. While there is continually compared: aural situation (in the sense of dynamic environment), evoked

responses (perception), evolution of form (structure definition) data preprocessing (material), patterns recognition from recorded data bases, and defining the data representation and evolution of the form. The observations are described in detail for each case study of dynamic soundscape environment.

*Motivation*

The purpose of this work is deepen and investigate the knowledge we have up today in field of advanced computer music techniques on their mathematical background along with the technologies and possibilities of computational architecture.

*Impact*

The outlined frameworks and models should introduce a novel computational architecture methods and strategies of architectural creative process and architectural thinking. Research outcomes will provide a number of frameworks and case studies that deal with complex dynamic environments from soundscapes, up to quantum level evolutionary architectures. It should strengthen the digital literacy and outline the possibilities in a domain such an architecture which supervise it self, challenge and questions on the edge of technical and artistic design methods. The research of advanced computer music and architecture defines link between these two domains where on the side of architecture is a number in space and on side of music is a number in time and with powerful machine learning models and algorithms we classify these numbers, reveal patterns and structure them into the coded evolutionary architectures like a living autonomous and intelligent organism.

## Discussion

The Intelligent Advanced Architectures, Generative Computer Aided Architecture, Advanced Computer Sound Synthesis, Natural Computing or Machine Learning are very progressive research fields, that this thesis adjust and refer to the results of recently published research and projects in these domains. Artificial Intelligence Architecture (AI-A) should react not only to the dynamic environment and balance the available energy resources and infrastructure,

but it should also consider the absorption, accumulation and energy distribution within the architectural body. The architecture that harvest energies and allow a balanced symbiosis of artificial, human and natural environment. Listed experimental projects explores trough the spatial sound, the possibility to expand our mental capsule into the physical world, shared environment, and allow it to be interconnected with the built reality that surrounds us.

Human tends to constantly transform the environment, everyone who moves through the architectonic landscape immerse within, search for forgotten spaces. Those spaces that are constantly transformed, by the memory, saturated with meetings and creation, from which we can draw fragments and patterns of randomness and the ability to adapt.

The thesis emphasise a framework of Evolutionary Convolutional Neural Networks, form finding methods, spectral analysis, and other methods for pattern recognition. It provides a starting point for researchers at all levels of experience, but especially for novice researchers, in refining the conceptual clarity of their inquiry.

**Research Contribution**

*What is the contribution comparing the recent design processes?*

Neuro-Evolutionary Architecture technologies allow us to monitor our neural, physiological and psychological responses that are measurable from biofeedback influenced by natural, human and artificial human environments and our social and cultural behaviours. They help us understand what is the impact of the architectural environment on our neural activity and nervous systems. We are able to observe both our conscious and sub-conscious responses on initiation sound signals. In this way we are able to better understand how our brain and body respond to internal and external consequences and expand the architectural tree dimensional space into correlations of the multidimensional experience of reality. The way we experience our inhabited space is limited by our imaginative ability to transform a matrix, with a relationship of evolutionary interactions and the polarisation of internal and external forces that are mutating in forms, functions and structures, purpose. The building is

understood as a dynamic organism that is driven by the creation of humans needs caused by the lack of instinctive adaptability.

This novel, authorial architectural approach, Architectural Intelligence, proposes a theory of architectural adaptive systems. Intelligence can be understood as a form of adaptation, while knowledge is based on two complementary processes of assimilation and adaptation[4]. Adaptation is an evolutionary process as a result of which the architectural body adapts better to a dynamically changing environment. If the organism cannot move or change enough to maintain long-term viability, it will obviously cause its extinction. In this perspective, Architectural Intelligence is a set of methods that adapt architecture to environmental and social change and instability. Architectural Intelligence is a method of solving architectural problems. I propose in particular the use of computer science techniques, deep learning and meta-learning, for the representation and analysis of complex architectural and spatial phenomena, for the search for and generation of optimal spatial forms.

Neuro-Evolutionary Architecture is an interaction between real, perceived, and imagined where actual leads into virtual and vice versa. It is an architecture that blends in and fills and dissolves these worlds in a form of impermanent narrative structures. The constantly presented true of limited three-dimensional illusion and continuous deceit is defaced.

In my work I outline new approaches to working with space, material and architecture of this space, sound-spatial structures are only one layer of the architecture of the future and the project Sound Shape Space is a case study of these new approaches, new architectures that work with current technologies and argue over technologies that we do not yet have available.

**Research Outcomes**

I developed Meta-Evolver, a tool for visual representation of dynamic environment models that correlate in a multilayer system (sound, neural activity, space). Meta-Evolver provides a virtual environment for testing dynamic spatial adaptation, where the environment consist of machine learning algorithms and parametrically defined geometry of space and integrates

the ability to interact with the human user. This tool uses advanced methods of artificial intelligence (meta-learning) and cutting-edge technology, including innovative methods of architectural creation, immersive environments and virtual environments. The ability to constantly learn and adapt with limited experience in a dynamic environment is an important milestone on the way of creating interactive and immersive spaces in architecture with various forms of intelligence.

**Architectural Intelligence**

An Evolutionary Architecture- John Frazer 1995. In the preface of the same titled book Gordon Pask mentioned that the fundamental thesis is that of architecture as a living, evolving thing. Architectural Intelligence integrates the natural processes and depart from the symbolical and metaphorical tectonic designing.

In nature it is only the genetically coded information of form which evolves, but selection is based on the expression of this coded information in the outward form of an organism. The codes are manufacturing instructions, but their precise expression is environmentally dependent, but as in the real world model it is only the code script which evolves.

The future is not given – it is under perpetual construction. The future emerges from the interaction of billions of current activities, natural and artificial.[5] The future architecture is capable of perceptual interaction with the environments, and stimulate construction and growth with regard to the needs of natural and artificial aspects of the specific environment.

This isn't a new idea, of course - it's ubiquitous computing, a concept that Mark Weiser introduced in 1991. *"The most profound technologies are those that disappear*," Weiser wrote: *"They weave themselves into the fabric of everyday life until they are distinguishable from it."* [6] We are entering the world of digital technologies and spaces filled with sensors and intelligence that becomes the material of our environments. It becomes our architecture.

To architect means to build a structure and relate detail to it. And when enters the role of humans in those systems, then it is architecture. There are conventionally trained architects

who make unconventional approaches to architecture and contribute in the design of complex systems. Whether it is conformable perspective or not, under this definition, we architect. Architecting permit an exploration of the mechanisms behind and within design, and expands the boundaries of practice. It provides the means to model the implications of computation, generativity, and intelligence.

Architecture is ahead of different technological paradigms, such as cybernetics and artificial intelligence, that architects explored at the scale of buildings and the built environment. How do architecting and architecture work when AI is part of the world around us, when algorithms determine so many aspects of our daily lives - our search results, the job postings we see, the movies we might watch, the people we might date? Those who design artificially intelligent systems don't make nouns-objects, buildings, things - they make verbs. They architect machine learning algorithms- the steps that a program will follow to complete a task. They put in place a set of starting conditions, after which the programs program themselves.[7]

But where are the architects and designers who design these algorithms into the built architectural environment?

**Defining Architectural Intelligence**

***Architectural Intelligence** is a set of evolutionary mechanisms that has a capability to adapt the architectural organism to the new environmental situation or behavioural patterns of it's symbionts, in a sort-term or long-term interactions. The **Architectural Intelligence** is both adapting, changing and accommodating the environmental dynamic and behavioural conventions. The architectural intelligence is taught by its architect.*

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***Intelligence can be seen as a form of adaptation in which knowledge is constructed by each individual through two complementary processes of assimilation and adaptation.[8] Adaptation is an evolutionary process as a result of which the body better adapts to a dynamically changing environment. If an organism cannot move or change enough to maintain its long-term viability, it will obviously go extinct.***

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*Future of Architectural Intelligence*

The future emerges from the interaction of billions of current activities, natural and artificial.[10] The future architecture is capable of perceptual interaction with the environments, and stimulate construction and growth with regard to the needs of natural and artificial aspects of the specific environment. Architectural Intelligence is a set of evolutionary mechanisms that has a capability to adapt the architectural organism to the new environmental situation or behavioural patterns of it's symbionts, in a sort-term or long-term interactions. The

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**Identification of Complex Systems**

The term complex systems often refers to the study of complex systems, which is an approach to science that investigates how relationships between a system's parts give rise to its collective behaviors and how the system interacts and forms relationships with its environment.

Urban and architectural structures are complex and multidimensional, intertwining natural processes with interactions between large groups of agents, communication flows,

information networks, and others. They undergo continuous transformation. The term evolving architecture refers to architecture that relies on physical and virtual processes that transform and assemble into structures in response to environmental properties and capabilities.[13]

A dynamic environment is any space that surrounds us and changes structurally over time, sometimes through modification by groups of agents. Spaces can be closed, with relatively well-defined boundaries, or open, without well-defined boundaries. Examples of confined spaces include homes, offices, hospitals, classrooms, and cars. Open spaces include streets, infrastructure nodes, plazas, parks, fields, air and the sea. The open space environments are usually rich, complex, and unpredictable; they can generate significant "noisy" data, and unstructured and sometimes very dynamic changes. This thesis investigates architecture as a living dynamic system as a complex set of natural and cultural sub-processes in which each interacting entity and system creates complex aggregates. The proposed dynamic models could employ various data, such as from human (transport, communication, information, technology), natural (wind speed, rain, temperature, tornadoes, floods and droughts) and biodiverse (microorganisms, animals,insects, plants) activities. Machine-learning methods make it easier to reveal and use correlations, patterns and transformations. About complex system such as architecture can be deduce very little from single series of numbers, but we learn much more when we can compare between different data series.

**Model**

*B-MAIA - Brain-Machine Artificial Intelligence Architecture*

The base for the very early research model framework draws from the concept of Nikola Kasabov and his book Evolving Spiking Neural Networks and Neurogenetic Systems for Spatio-and Spectro- Temporal Data Modelling and Pattern Recognition.[14]

Regarding Kasabov BI-AI systems[15] have six distinctive features:

1. They have their structures and functionality inspired by the human brain; they consist of spatially located neurons that create connections between them through deep learning in time-space by exchanging information—spikes.
2. Being brain-inspired, BI-AI systems can achieve not only deep learning, but deep knowledge representation as well. They are transparent.
3. They can manifest cognitive behaviour.
4. They can be used for knowledge transfer between humans and machines as a foundation for the creation of symbiosis between humans and machines, ultimately leading to the integration of human intelligence and artificial intelligence
5. BI-AI systems are universal data learning machines, being superior than traditional machine learning techniques when dealing with time-space data.
6. BI-AI systems can help understand-, protect-, and cure the human brain.

Some of the very first models of the spatial emotion recognition were based on the medical research and theoretical work of Hugo Lövheim and his concept of Cube of Emotion.[16] Lately there was made an another research by Jordi Vallverdu in collaboration of Hugo Lövheim and his goup presented at The 9th Annual International Conference on Biologically Inspired Cognitive Architectures, the Ninth Annual Meeting of BICA Society in Prague.[17] Or recently extended idea of Cube of Emotion in the Neuropunk Revolution research.[18]

## Complex Dynamic Environment Models

More contextual shape and consistency of the whole model was finally achieved through studying architectural environment and behaviours as a complex system and dynamic environments.

*Dynamic environments*

Urban and architectural structures are complex multi-dimensional structures in which natural processes and interactions of large groups of agents, communication flows, information

networks, and others are intertwined. The above structures undergo continuous transformations. A dynamic environment is any space that surrounds us and the structure of which changes over time or is modified by groups of agents. There are closed spaces with relatively well-defined boundaries and others that do not have well-defined boundaries, which we can call open spaces. Examples of confined spaces include homes, offices, hospitals, classrooms, and cars. Examples of open spaces are: streets, bridges and parking lots, fields (in agriculture), air (in the case of airplanes) and the sea (for underwater pollution measurements and tsunami early warning system). These environments are usually rich, complex, unpredictable, and can generate significant "noisy" data, unstructured and sometimes very dynamic changes.

*Environmental modelling*

One of the task of this work was to establish and model an environment which could simulate and, more importantly, influence the performance of the evolving model.

*Experiment Model - see the next page*

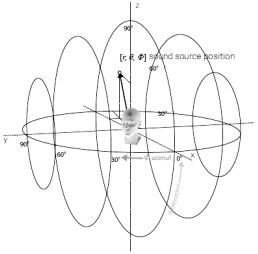
In the experiment, was found certain relationship between sound and space, respectively an image of this space that the brain creates based on the perception of this sound. I consulted with the IIM (Institute of Intermedia, FEE CVUT) with Michal Rataj (HAMU) Ambisonie, and Zdeněk Otřenášek (MARC - Music Acoustic Research Center) measuring EEG with EmotivEPOC, and psychoacoustics. Based on several consultations, we came to the conclusion of simulating everything in VR, including the "soundscape" sound experience, when in a virtual 3D environment, a sound environment is created, and this environment simulates the spatiality of sound into headphones. However, this leads to problems, the VR headset and the device (Emotiv EPOC) for measuring and recording EEG we no longer get on the volunteer's head. NeuroCap with the professional support of NUDZ (Iveta Fajnerová) and COGSYS CIIRC (Lenka Lhotská) was used for the implementation of the experiment and EEG measurements. The output of this experiment is two types of data streams: a) data stream with information about the position of the sound source and its characteristics (sound stimulation) Ambisonics PureData and SuperCollider b) dataset with recording from EEG (ie recording how sound affected a person at a given moment, resp. adapts more effectively to dynamic conditions.

Being sensible demands recognising the user, learning or knowing their preferences and the capability to exhibit empathy with the user's mood and current overall situation. Different users have different preferred modalities of interaction (e.g., auditory, visual, tactile, etc.), this is shaped by education or it could be affected by physical and cognitive capabilities. A system that wants to effectively engage with a user should be prepared to offer assistance in a variety of combinations. Humans have different attitudes towards privacy, generally this is a sensitive issue for most people and as such it should be approached with care and

## Soundscape

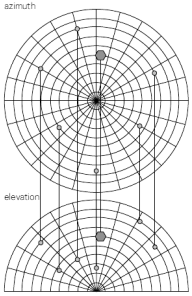
**ambisonic sphere - spherical coordinates**

$r$ - radius
$\theta$ - elevation
$\Phi$ - azimut




**Sound source position**

azimuth




**Referebce sound field sphere**

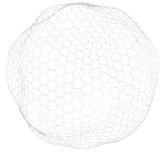
The Surrey Sound Sphere (pictured) is used for advanced sound field rendering and perceptual experiments. Such technology could be adopted in open plan living spaces, where multiple occupants consuming audio content would not have to wear headphones. The sphere has allowed different design approaches to be implemented, measured, and evaluated by panels of listeners. The sphere has also been used for perceptual experiments around human localisation of sound sources.
(The Engineering and Physical Sciences Research Council (EPSRC))

**VR soundscape controled by PureData**

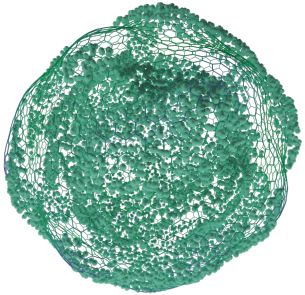


Ambisonic Sound Sphere Field in VR created with Ambisonic Tools for Pure Data provides a controled dynamic sound environment generated and observed by machine learning algorithm

**Sound Spetrogram Field**

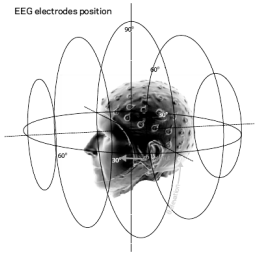


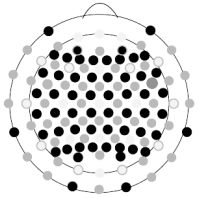
Sound Sphere Stimuli Spectrogram controled dynamic environment model observed by machine learning algorithm



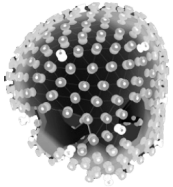
## Interpreter - Brain Dynamical Response

**EEG electrodes position**



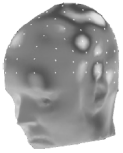



Full 10–5-system. Additional electrode positions in the 10–5 system are indicated by white circles. Standard and extended electrode arrays are indicated (black electrodes: 10–20 system, gray electrodes: 10–10 system, with permission from Oostenveld and Praamstra (2001)).



256 electrodes projected onto a 3D healthy human brain. Note the improved spatial sampling from most of the cortical areas (by Laurent Spinelli, University Hospital of Geneva). High-density scalp EEG arrays (64–256 electrodes) allow source imaging with even sub-lobar precision.

**Response Topographical Map**



ERP 300 - Evoked Response Potential Dynamic Field 3D topographical scalp maps of brain wave band power

**Interpreter Responce Dynamic Field**



Topological map of EEG ERP 300 mapped on reference space of controled dynamic environment model observed by machine learning algorithm

implemented with the assumption that the user value privacy and is allowed to set up how the system should deal with issues that relate to privacy. Safety is another important aspect a system will be forced to look after, given this systems primordial role is to assist humans, failing to preserve the safety of humans will render any such system worthless and unusable.Systems in this area are expected to have a degree of autonomy, the more autonomy the better, provided this does not come at the cost of other principles like safety. The system should be able to inform itself by learning from previous experiences and its intelligence should help adaptation to different circumstances in such a way that it does not require continuous programming.

A fundamental principle to be observed is that users should be always in control and should be able to decline advice from the system, impose their preferences, undo previous decisions and actions from the system and even disconnect the system altogether if it is perceived inconvenient. Systems of this type should be immersed in the environments we inhabit. Meaning their introduction to the environment and humans which were part of is the space is having to adapt to or change than the fundamental interactions and behaviours.

### Quantum based model

Quantum theory in the context of architectural modelling describes a deeply interconnected world that recombines objectivity and subjectivity, quantitative and qualitative, mind and matter, into a unique model of Architectural Intelligence a reality.

## Experimental Works of Dissertation

### Self-Evolved Architectures

The early stage of research experimentation with the simple neural networks and basic machine learning technics, outlined a need of more general framework for optimization and adaptation of architectural space. The basic generative methods as a results of the data processing from the digital environment could not reach the complexity of the proposed

framework of Quantum-model for Architectural Intelligence. The genetic and evolutionary algorithms had to be applied to the model.

*Experimental work published on GitHub*

### Appendix A: Self-Evolved Architectures

*https://github.com/kaiakk/Self-Evolved-Architectures*

Evolving Architecture uses the features of natural design processes and relies on dynamic adaptation to environmental changes. The analogies of evolving architecture should be understood not only in terms of the applied natural processes of development of forms through natural selection, but also in the restless tendencies towards optimization and self-organisation that significantly improve the efficiency and power of diverse prototyping. Architecture is design to survive, design for life, and emphasizes the need for a responsible approach to the transformation and formation of energy and materials. The solution to dynamic environmental problems is to link architecture with a contextual understanding of the structure of nature. Traditional documentation of architectural production and construction design is replaced by code as a set of instructions and calculation formulas that reflect and adapt to a specific dynamic environmental and spatial context. The proposed approach to understanding and designing architecture introduces a set of instructions that John Frazer called "the genetic code of architecture."

At the same time, in computer science, methods inspired by the process of natural selection such as genetic algorithms have been developed widely, e.g .: design, games, image processing and robotics. Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on biologically inspired operators such as mutation, crossover and selection. A particular example is Hyper-NEAT, which can be used to transform 3D objects. The principle of the algorithm is the simple weight evolution in a topologically static neural network (CNE) or the evolutionary adaptation of the covariance matrix (CMA-ES) strategy, to the weight and topology evolution (NEAT) and intermediate weight coding (HyperNEAT). All algorithms encode artificial neural networks

(ANNs), which are represented by weights and connectivity (also called topology). The first two algorithms only search the ANS weights, while the last two can also modify the topology.[19]

**Meta Architecture**

The goal of Meta Architecture framework is to create new support tools in the form of software for researching and developing evolutionary architecture, that intervene and create relevant quality to the conditions of the environment. This research is fundamental to an architecture of the future that will be well adapted, in particular a flexible safe architecture that accommodates mass migrations and environmental climate crisis situations or global pandemics. Following framework was investigated through several experimentations with machine learning techniques.

Meta Architecture is a set of trained neural networks (artificial agents) that adapts quickly to the new environment. The neural networks are trained to learn something transferable that helps to generalize the situation or the scenario of the environment. Trained networks have a good performance after the adaptation stage, while it will update its current policy to fit its current environment.[20] Meta Architecture is not learning how to master a particular task but how to quickly adapt to new tasks. -Meta-Reinforcement Learning.  Meta architecture is an intelligent agent (framework) that monitors the virtual world and intervenes to drive the architectural space forward according to some model of quality of experience.

*Experimental work published on GitHub*

Appendix B: Meta Architecture

*https://github.com/kaiakk/Meta-Architecture*

*Meta-learning*

Meta-learning goes by many different names: learning to learn, multi-task learning, lifelong learning, transfer learning, etc.

Transfer learning is the improvement of learning in a new task through the transfer of knowledge from a related task that has already been learned.

This approach for analyzing and creating evolving architecture is based on meta-learning. Meta-learning is the next generation of artificial intelligence systems. Meta-learning goes by many different names: learning to learn, multi-task learning, transfer learning, zero shot learning, etc. People easily transfer knowledge acquired in solving one task to another more general task. This means that we naturally recognize and apply previously acquired knowledge to new tasks. The more the new task is related to our previous experience, the easier we can master it. In contrast, popular machine learning algorithms deal with individual tasks and problems. Transfer learning attempts to change this by developing methods to transfer knowledge acquired in one or more source tasks and using them to improve learning in a related target task. The goal of transfer learning is to improve learning in the target task by using knowledge from the source task. Techniques enabling knowledge transfer will constitute significant progress in AI and and architecture.

*Meta Architecture (MA) Framework*

MA must generally look ahead into possible futures of the user's experience to determine the best intervention, if any, to bring about a structurally coherent experience.

MA user has opportunities to act, lead, MA must continuously project and select possible future scenarios.

**Meta Evolver**

Meta-Evolver[21] is a tool for a visual representation of the various dynamic environment models that correlate in multi-layered system. Meta-Evolved provides the environment for testing dynamic spatial adaptation, where the environment is composed of algorithms and parametric definitions.

Figure: Evolving Architecture, based on Meta Architecture Framework, 2020, Meta-Evolver tool Karolína Kotnour.

*Experimental work published on GitHub*

## Appendix C: Meta-Evolver

*https://github.com/kaiakk/Meta-Evolver*

This research uses advanced AI methods (meta-learning) and cutting-edge technologies including immersive environments and virtual reality (VR) to offer innovative methods of architectural creation. The ability to continuously learn and adapt from limited experience in a dynamic environment is an important milestone on the path towards building interactive spaces in modern architecture. We developed the tool Meta-Evolver for testing spatial adaptation in dynamic environments and integrated the ability for interaction with a human user.

*Evolving Architecture*

Evolving Architecture is a large field with a few subfields such as Prescribed, Responsive, Interactive and Evolutionary or Living Systems. Each of these areas need different expertise and often focused on certain interaction strategies and techniques as practiced by people like Michael Fox, Rachel Armstrong, Philip Beesley or Heatherwick and UN Studio. Evolving Architecture uses the features of natural design processes and relies on dynamic adaptation to environmental changes. The analogies of evolving architecture should be understood not only in terms of the applied natural processes of development of forms through natural selection, but also in the restless tendencies towards optimization and self-organisation that significantly improve the efficiency and power of diverse prototyping. Architecture is designing for survival, designing for life, and emphasizes the need for a responsible approach to the transformation and formation of energy and materials. The solution to dynamic environmental problems is to link architecture with a contextual understanding of the structure of nature. Traditional documentation of architectural production and construction design is replaced by code as a set of instructions and calculation formulas

that reflect and adapt to a specific dynamic environmental and spatial context. The proposed approach to understanding and designing architecture introduces a set of instructions and general principles of interaction with the environment that John Frazer called "the genetic code of architecture."[22] It is also necessary to create large groups of researchers, architects and urban planners that change and adapt the architecture of our cities and suburban to the new needs of their inhabitants.

At the same time, in computer science, methods inspired by the process of natural selection such as genetic algorithms have been developed widely, e.g .: design, games, image processing and robotics. Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on biologically inspired operators such as mutation, crossover and selection. A particular example is Hyper-NEAT, which we used to transform 3D objects. The principle of the algorithm is the simple weight evolution in a topologically static neural network (CNE) or the evolutionary adaptation of the covariance matrix (CMA-ES) strategy, to the weight and topology evolution (NEAT) and intermediate weight coding (HyperNEAT). All algorithms encode artificial neural networks (ANNs), which are represented by weights and connectivity (also called topology). The first two algorithms only search the ANS weights, while the last two can also modify the topology.

This model proposes a neuro-evolutionary algorithm for Architectural Intelligence and the quantum architecture model is based on HyperNEAT, Neuroevolution of Artificial Neural Network Topologies.[23], [24], [25], [26]

**Meta-Evolver Framework**

The framework for the adaptive agent-based model for dynamic environments based on data of generated random numbers and soundscape was defined. We outlined and established the architectural strategy of the multi-platform system for generative modelling based on input datasets. The framework for a visual representation of the dynamic models and generated resulting correlated layers. The main task was adapting an agent to new environments and create a new multi-agent environment as well as architecture for testing aspects of continuous adaptation. The whole model was parameterised and the

communication protocols integrated into the digital environment. The method was to present dynamics as a sequence of tasks and train agents to use the dependencies between successive tasks. We created a meta- learning model for the problem of continuous adaptation of an artificial agent in a complex dynamic environment.

The observation-based research on these generated correlations was conducted and defined the possible dispositions of forming patterns and structures, the model can be applied to various dynamic environments and after pre-training of agents can effectively adapt and, generate architectural dispositions, structures, and environments. The parallel task of my research was the problem of creating virtual interactive environments (VE). We were focused on the roles of Presence, Flow, Immersion, and Interactivity. Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another. Presence is a normal awareness phenomenon that requires directed attention and is based on the interaction between sensory stimulation, environmental factors that encourage involvement and enable immersion. Flow is a state of experience where someone is completely absorbed and immersed in an activity. We researched relations between presence, flow, immersion, and interactivity, e.g. how interactivity and sound spatialization improves the experience of presence. The three different and complementary 3D environments and experiments: 1) adaptation in a dynamic environment created by changes in the structure of the parametrized environment; 2) adaptation in a multi-agent environment created by the presence of multiple learning actors (interdepended datasets, transformation matrices), and 3) adaptation in a dynamic environment created by the interaction of a human user with an adaptive artificial agent. The immersive dynamic environment is created by using virtual reality (VR) and sound synthesis. The model keeps the transformation of 3D objects and sound synthesis as synchronous processes.

**Conclusion and Future work**

The Advanced Architecture Approach is in digital writing and coding of life. The digital articulations of artificial life, and the diversity of artificial entities are depending on the levels of abstraction from the complexity of multilayered environment. The writing and coding as a

core proficiency of architects represents a radical revolution for architectural design. While this techniques relies on the one hand on the advances in computational power of computers and computational technologies and on the other hand on the power of digital representation, and intervention to the environment. The Advanced Architecture Approach works with digital models that are either rule based models, control based models, or quantum based models. Where the quantum models describes a deeply interconnected world that recombines objectivity and subjectivity, qualitative and quantitative, mind and matter, into a unique model of reality.

Neural networks are universal function estimators. Universality means that neural networks can approximate many different complex functions. The main idea of neural networks is to build up representations for complicated functions using compositions of relatively simple functions, which are called layers. The proposed model suggest combination of simple functions in more complex functions that defines architectural environments and demands on architecture that *Architectural Intelligence* system can learn. Machine learning tools are support tools for improving design processes. They are form of navigation system for an architect whose role is that of an operator of the design processes and who maintain the intelligent system during learning.

The proposed *Architectural Intelligence* model of neuro-evolution and meta-learning models provides variability and flexibility in dynamic environments. Meta-learning approach provide sustainable possibility of implementing already tested and trained models from other domains and areas of machine learning to the field of architecture. The above research is fundamental to an architecture of the future that will be well adapted, to the changes defined as differentiations of the environment, in particular resilient architecture that accommodates mass migrations and environmental climate crisis situations or global pandemics.

Meta Architecture and Self-Evolved Architecture frameworks investigates fundamental form-generating processes in architecture, paralleling a wider scientific search for a theory of evolution in the natural world. In evolutionary processes, the new forms are created by structural modifications of old forms. An evolutionary environment maintains a hierarchy of long and short term purposes and modifications, where each of this purpose has its own

dominant periodicities. The domain of Evolutionary Architecture is a large field with a few subfields such as Responsive, Interactive and Evolutionary or Living Systems. Where each of these areas need different expertise and often focuses on certain interaction strategies and techniques.

The fundamental need and motivation for communication and movement is determined by physiological and psychological possibilities and needs of living organisms. Naturally these processes, which are largely determined by available technologies, creative and intellectual activities, are in the balance of all layers of architectural environment.

The character of space is given by the ability to communicate and the need to communicate and understand.[27] The resulting architecture should be able to accommodate these human needs as flexibly as it adapt and assimilate dynamic forces of the environment.

The *Architectural Intelligence* allows to communicate and interact with the inner and outer space in time and in constant tension of two dynamic forces. The structure of meta-space suggested  in this thesis primarily create for its user-creator-agent environment based on the uniqueness and users perception of the environment.
Neural Architecture Search and Future work

The architects are engaged in designing systems containing the architectural problems and computational models for their solutions. The future challenges and demands on meta-learning or quantum-learning consist of capability of self-observation of the routine in creative design process, the perception action loop.

In terms of Architectural Intelligence the new support tools in the form of software for researching and developing evolutionary architectures should be build.

List of dissertation works related to the dissertation/ Seznam prací disertatnta vztahujících se k disertaci:

This research was supported by CTU grant SGS19/117/OHK1/2T/15.
Title: Evolving Architecture - Adaptation of Artificial Neural Networks in Complex Dynamic Environments
This research was supported by CTU grant SGS17/117/OHK1/2T/15.
Title: Generated Spatial Models and Architectural Forms of Soundscapes

## Conferences

eCAADe 2017, Sharing Computable Knowledge,
ShoCK! Sapienza University of Rome Italy, PhD award
IRCAM Forum 2018, Centre Pompidou, IRCAM Paris, France
RIS eCAADe 2018, Cyprus University of Nicosia, Nicosia, Cyprus
DCC 2018, Design Computing Cognition, Milan Technical University, Lecco Milano, Italy
HLAI 2018, Human Level AI Conference, Prague, Czech Republic
AAG 2018, Advances in Architectural Geometry, Gotenburg, Sweden
MurmurandusMundus 2019, UnL, CZ
ZIP Scene 2019, Moholy-Nagy University of Art and Design Budapest, HU
360 degrees Gallery, 2020, Cracow, PL
SigGraph, 2020, ACM SIGGRAPH Conference and Exhibiton on Computer Graphics and Interactive Techniques, Virtual Asia
Art Machines, 2021, City University of Hong Kong, HK
Des(AI)gn, 2021, Holon Institute of Technology, Holon, IL
Workshops and posters
conference Forum IRCAM poster session
conference DCC´18 - Design Computing Cognition
conference eCAADe Regional International Symposium 2018
Presentations
IRCAM Forum Paris - featured speaker, Centre Pompidou, IRCAM http://forumnet.ircam.fr/forum-ircam-speakers-bio/
eCAADe RIS Cyprus University of Nicosia,
eCAADe RIS 6th regional symposium, Department of Architecture, University of Cyprus, Nicosia, Cyprus
AURAL VIRTUAL WORLDS - NOISES, SIGNALS, HUMAN BRAIN INTERFACE AND AUDIO-VISUAL PROGRAMMING
Sustainable Computational Workflows [6th eCAADe Regional International Workshop Proceedings / ISBN 9789491207143], Department of Architecture, University of Cyprus, Nicosia, Cyprus, 24-25 May 2018, pp. 5-14 http://papers.cumincad.org/data/works/att/ecaaderis2018_000.pdf
DCC 2018 - 8th International Conference on Design Computing and Cognition DCC´18 Bringing artificial intelligence, cognitive science and computational theories to design research 2-4 July 2018 Politecnico di Milano, Lecco Campus on Lake Como (near Milan), Italy proceedings by Workshops 30 June - 1 July 2018 http://dccconferences.org/dcc18/
Teritoria Umění 2018, Mezinárodní vědecká konference doktorandů uměleckých škol, AURÁLNÍ ARCHITEKTURA: BUDOVA JAKO KOGNITIVNÍ ENTITA In: Teritoria umění 2018. Praha: NAMU - Nakladatelství Akademi múzických umění v Praze, 2018. http://teritoria.amu.cz
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KOTNOUR, K. and R.B. LISEK. Evolving Architectures - Spatial Adaptation in Multidimensional Complex Dynamic Environment. Technoetic Arts. 2020, ISSN 1758-9533. Before publishing (2021)
KOTNOUR, K.; FLORIÁN, M.; LISEK, R.B. Architectural Intelligence - Meta-Learning Methods for Spatial Adaptation Leonardo. 2021, ISSN 1530-9282. Before publishing (2021)

## Web Publications

https://www.researchgate.net/project/Evolving-Architectures-Spatial-Adaptation-in-Multidimensional-Complex-Dynamic-Environment
https://www.researchgate.net/project/Architectural-Intelligence-Meta-Learning-Methodsfor-Spatial-Adaptation
The software "Meta-Evolver" and algorithms and parametrized environment were made accessible at https://github.com/kaiakk/Meta-Evolver
The documentation of the 3D dynamic environment and machine learning algorithms is accessible at https://github.com/kaiakk/Meta-Evolver/blob/main/README.md
The research project page can be found at http://vr.molab.eu/category/research/karolinakotnour/

## Lectures

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SIGGRAPH Asia 2020 VIRTUAL. Daegu, 2020-12-10/2020-12-13. New York: ACM SIGGRAPH, 2020. Dostupné z: https://sa2020.siggraph.org/en/submissions

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Feedback/ No feedback or citations known to me.

Resumé

Karolína Kotnour, Ing. Arch., is an architect and artist dedicated to an architectural spatial and audio-visual production. She is focused on creating future evolving architecture by transforming methods from neuroscience, machine learning, immersive and sound spatialisation research. In her projects and installations, she connects and synchronises architectural and sound structures. She claims "*the reciprocal confrontation of sound waves as is a liberated contour of space*". She interests in "*space as evolving over time, in parallels and mutual confrontations and reflections*". A significant role plays human acoustic presence and performance. She observes extreme space phenomena e.g.: *„acoustic black holes"* and transformation of sound vibrations in their surroundings. She is Ph.D. research fellow at FLOW studio at Faculty of Architecture CTU in Prague.

Karolína Kotnour, became a member of the Studio FLO|W in 2015 and from the very beginning she has been a leader. Her talent in the independent and creative approach to solving the projects has predetermined her to reaching excellent results in her studies. Hard work combined with efficiency is the motive power of Karolína Kotnour, whether in having a lecture /e.g. eCAADe, IRCAM Forum Paris, or Artificial Intelligence Centre Prague, contributing in exhibitions such as 13th Architectural Biennale in Venice with work on a sustainable future for Greenland /Migrating Greenland/. Karolína continuously specialised self-education in field of advanced architecture, media arts, graphic design, fabrication and the follow-up fields such as domains of cognitive sciences not only in the context of Czech Republic, but also abroad for instance the co-operation with David Garcia Studio, MAP architects, Active City Transformation, Henning Larsen Architects, Denmark Copenhagen. Karolína Kotnour is authority in the field of theory and practice of advanced machine learning methods in architecture and media arts, BCI technologies in immersive arts and architecture. Architect Karolína Kotnour contributes by her active approach and with her reached results to keeping up a high level of the results of the studies at the Studio.

Architect Karolína Kotnour has been engaged in research in the field of architecture for a long time. Her early activities include Urban Sprawl Research Project at TU Dresden, further research with Copenhagen's Henning Larsen Architects / MAP in the area architecture in extreme socio-environmental conditions and more recently the development of a digital imaging tool city sensory data in cooperation with CIIRC within the Virtual Prague project. Three years ago she was invited to IRCAM Forum in Paris as a featured speaker with the contribution of Sound Shape Space. In addition, Karolína regularly participates not only in domestic but especially in foreign conferences, at which presents and publishes the results of his work. Again, I give three samples for all: participation in the Des(AI)gn conference in Holon Institute of Technology Israel by Neural Architecture Search contribution. Evolutionary Strategies for Architecture, Art and Design, then participation in the Art Machines conference at the City University of Hong Kong with the contribution Meta-Evolver, Evolutionary Strategy for Architectural Intelligence and participation in the International Journal of Technology, Knowledge and Society conference at the University of Illions with a contribution to Evolving Architectures. Everywhere she presented the research on which hers is based dissertation, which focuses on the adaptation of architecture to the dynamic environment of sound spaces. It applies in it algorithmic models of machine learning and defines the *Architectural Intelligence* based on evolutionary strategy and meta-learning. Karolína's research was repeatedly supported not only by grants in the framework of the student grant competition at CTU, but also by grants international cooperation and scholarships for PhD students from Computer Aided Architecture Design.

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