NEW GENERATIVE AND AI DESIGN METHODS FOR TRANSPORTATION SYSTEMS AND URBAN MOBILITY DESIGN, PLANNING, OPERATION, AND ANALYSIS: CONTRIBUTION TO URBAN COMPUTING THEORY AND METHODOLOGY

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ABSTRACT

The paper places its contribution within the domain of architectural and urban computing, artificial intelligence application in urban and architectural studies, or more broadly in spatial and urban planning, analysis/analytics, design, and operation, all considering new methodologies. Having new computational design and problem-solving methods in mind as a primary investigative subject and instrument (AI and generative design methods in particular), the author aimed to test the range of possibilities of their application in the named contribution area, forming corresponding theoretical foundations of thus established design and research conduct. Such an aim demanded an elaborate theoretical review so as to provide the necessary background for understanding the most recent stage of technological development within the digital architectural, urban, and spatial design and computing, valid corresponding terminology, groups of targeted computational design methods, and available software tools for their application, all within the functional systematic cross-disciplinary approach to the construction of design problem-solving methodology with regards to spatial and data/computational sciences. The approach has been interpreted through condensed tabular and diagrammatic information on conducted case studies, used to support, and illustrate stated theoretical objectives.

Due to the large area of application, the focus of the more specific inquiries has been narrowed to one of the urban systems and planning concerns - the urban mobility and transportation system - first by employing all its modalities, urban infrastructure, and facilities on a larger scale to define operative research environment, and second by targeting specific design questions and tasks within the defined domain, including examples of the ways in which they can be modeled as abstract or real-world problems. The Grand Paris transportation network and region have been chosen for the experimental field of operation, while supportive material for establishing generative design problem modeling and solution methodology has been provided through specific tasks addressing network graph design and operationalisation, and urban movement design through selected computational problem-solving methods.

KEYWORDS _ *urban and architectural computation, computational design methods, generative design, artificial intelligence, urban networks, network graphs, spatial information, and intelligence systems*

Introduction: the research structure and main objectives

Digital tools and computing methods in architecture and urbanism are fundamental to new design frameworks, including all phases of the design process – conceptualisation, planning, data acquisition, visualisation, production of technical documentation, and various forms of postproduction and media representation. The most recent digital technologies have once more induced innovative design conducts, opening up new ways of performing urban and architectural design tasks and offering new methods for solutions to various design problems related to both research and practice. As their integral part, software operations based on AI and generative design principles have been investigated, and some preliminary conclusions regarding one of the defined design problems and its set of solution methods have been theoretically framed.

The presented research project on mobility has been settled between urban and architectural studies on the one side, and data and computational studies (AI in particular) on the other. It has been devised in a manner that practical investigations, following design research methodology (research *through* design), have been reflected upon through a theoretical review of terminology, interdisciplinary relations, and methods that can be used in the construction of the wider computational problem-solving methodology for the defined spatial design problem. The research practice is thus tightly embedded into the theoretical and methodological considerations, which have been the primary focus of the paper. It is represented through illustrations and conclusions based on practical test results. The paper has been organised into three parts. Firstly, a generative design problem and task considering the chosen area of urban mobility and transportation networks has been provided. Introduced by an illustration of the performed analysis of one branch of the solution methods, a part of the set defining problem-solving methodology (Fig. 1), it opens the theoretical discussion and explanations of further targeted subjects of the paper. Addressing the cross-disciplinary positioning of the research subject and performed practical analysis, the second part then covers investigations of the most important task issues concerning terminology and organisation of the problem-solving methodology through phases (Table 1). Aiming to establish a proper collaborative and relational investigative framework that supports integrative forms of action of involved disciplines, it refers to already performed practical design research and grounds the suggested sequences of research phases on its results. Such reflective practice, which models the problem-solving set of methods containing design problem definition, solution steps, design instructions, and main concepts, can be easily linked to graphic documentation of exercises performed for development phases, too. The third part focuses on computational methods and computational design taxonomy which construct the overall problem-solving methodology used in tests. It comprises discussions on computational, AI, generative, and graph design methods, herewith targeted to be used in urban planning, design, and analytics, and to be set in relation to the chosen urban mobility problem. The final composition of performed theoretical and methodological studies supported by practical design research material is thus prepared for the last phase of the design problem investigation, as has been announced in the concluding remarks alongside the summary, recommending further expert AI comparative analysis.

Urban mobility and transportation system design problem definition

The problem chosen for investigation has been defined as follows*: Generate an urban movement path of an agent along the lines of the city rail transportation system while being guided by relations between the states/points within its network (distance, proximity, thematic character, frequency, etc.) and landmark class of destinations (Fig. 1). Define parameters for path character, movement objectives, constraints, policies, and movement agendas. Suggest path increment options in each state and continue the process after a decision has been made (a new state has been occupied) with feedback propagation to be included in statistical analysis and improve new playouts*.

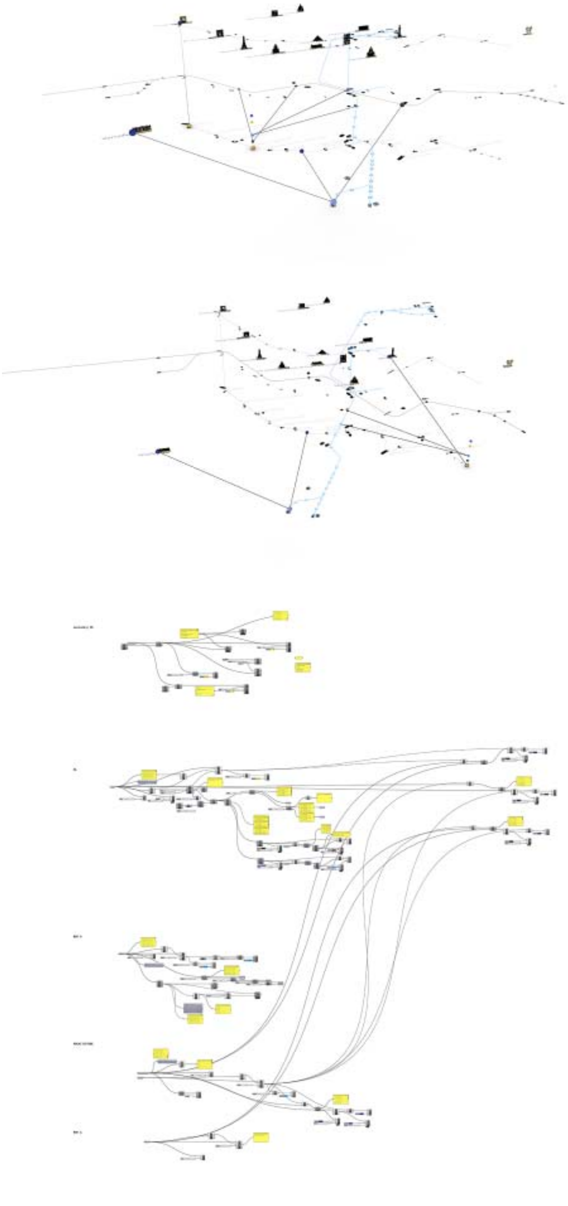

Figure 1. Simulation of the agents' movement along the metro lines while the two closest points on the targeted destination or transition metro line and the closest landmark destination are displayed (lines represent possible actions, while points represent states that can be occupied as a part of the movement sequence). Animation and programmed sequence - Rhinoceros, Grasshopper. Source: © Dragana Ćirić, unit [d], 2023. Animation: https://media.licdn.com/dms/image/C4E22AQF4E7VO9QNEcA/feedshare-shrink_2048_1536/0/1674356092813?e=1696464000&v=beta&t=NfGibxnkvhfV2lxzVGChJYjyIlTSsm9VkQYO99LPnYM.

CHALLENGES OF INTER- AND CROSS-DISCIPLINARITY: URBAN AND ARCHITECTURAL PLANNING, DESIGN, AND ANALYSIS IN RELATION TO COMPUTING, DATA SCIENCES, AND ARTIFICIAL INTELLIGENCE

The preliminary phase of the interdisciplinary collaborative practice involving the fields of architectural and urban studies, and computer and data studies, has had as a major concern the theoretical and methodological basis regarding the competencies of architectural and urban planners, designers, or scientists in regard to the defined problem. Such concerns are important for unambiguous cross-disciplinary communication between the parties involved, as well as for gaining important insights into the field of competence of research collaborators, including required qualifications, and design/research skills. Since each collaboration within the interdisciplinary alliance presents a learning process, a proper collaborative method and framework could prevent setbacks regarding communication or efficiency, and lead to the best research results. In addition to conceptual and terminological aspects, the operational one has the executive strategy and logic at the centre of interest. The set of problem-solving methods, or conduct instructions, complements established cross-disciplinary foundations, and gives way to exchange between the disciplines at the methodological level, as well.

Prior to more detailed explanation of performed urban systems analysis or analytics using AI methods (computer and data sciences and representation in general), the common ground of two main research fields had to be established. As is usually the case, the terminologies used by both areas may coincide, yet imply different meanings, scopes, actions, and procedures. Thus, vocabulary and taxonomy have been investigated in order to obtain the highest degree of clarity in interdisciplinary communication. The table of terms used in architectural and urban studies, and computational and data sciences, along with definitions used by both areas to describe and represent the same entities, and formulas for the execution of related operations, has been created and organised in a sequence of actions of the design problem, parameters and solution methods definition. Such approach helps in establishing clear relations between the ways in which required terms and stages of the design problem definition and solution are posited by computer and data sciences and by architectural and urban sciences, all leading to conclusion suggesting formulation of the glossary as a precondition for investigating the targeted interdisciplinary area of architectural and urban computing.

Design problem definition has, in itself, a disciplinarily-specified and shaped usage. This is reflected in terms and methods that each discipline treats, interprets, constructs, and applies differently, along with the design problem development and solution phases. While aiming to set them in an operative mode – a computationally comprehensible and executable set of actions (Table 1 horizontal rows) – Table 1 provides evidence for some of them (e.g. environment, maps, agents, network graphs, geometry, etc.), rendering precisely their semantic and operative interpretation by both disciplinary tracks – the perspective of urban design, planning, and analysis along the one track, and computer and data sciences along the other (Table 1 vertical columns). The table refers to specificity of the generative design problems investigated herewith (urban mobility and transportation systems tasks). Yet, its structure and course of procedures from design problem definition to solution might well become the key for more general methodology and construction of its model (*problem-solving model construction*) implying application to more examples and in a much wider context.

Considering the latter, as demonstrated in Table 1, the phases of the design problem definition and conduct (a set of methods towards the solution) in general terms, include specification of the following: 1. environment/simulation environment (data model and spatial model), 2. parameters (categories and taxonomy), 3. objectives and/or constraints, 4. external policies and strategies/objectives or factors that influence them, 5. problem-related data acquisition, 6. model parametrisation, 7. probes of sequential functions and methods, 8. final subspecification of a design problem, and 9. design problem conclusion. The last two phases based on design problem specificity, branch according to its decomposition (along the tracks *a* (system) and *b* (action within the system)), influencing interactively the number of possible end-solutions within the given model and frame.

Table 1: Design problem modelling: disciplinary framed terminology in data sciences/mathematics and architectural and urban sciences - communicative interdisciplinary platform and terminology comparison as applied in and organised for design problem and research development phases. Source: ©Dragana Ciric.

Design problem modelling and problem-solving set of methods development steps/phases and concepts		Urban mobility planning, analysis, and design perspective		Mathematical modelling perspective	
01					
ENVIRONMENT		**ENVIRONMENT/SPACE**		**PROBLEM SIMULATION ENVIRONMENT**	
SPATIAL FRAMEWORK CONSTRUCTION AND MODELLING WITH AND WITHIN WHICH AGENT(S) WILL INTERACT	**REAL-WORLD ENVIRONMENT**	**REAL-WORLD GEOMETRY, MAPS AND 3D MODEL**		**CODE / ALGORITHMS / GRAPH**	
			GEOGRAPHIC LOCATIONS / AREAS / ELEMENTS - GEOGRAPHICAL COORDINATES		
			TRUE DISTANCES (SCALABILITY)		
			PROJECTIONS AND IMPORTED WORLD MODELS - CURVED GEOMETRY		
			REPRESENTATION THROUGH LAYERS AND STACKING		metadata (streets, roads, objects, landscape, waters, etc.)
	ABSTRACT ENVIRONMENT	**GEOMETRY OF URBAN MOBILITY SYSTEM – TRANSPORTATION LINES AND DESTINATIONS, INCLUDING OTHER POINTS OF INTEREST ON SEPARATE LEVELS**		**NETWORK GRAPH/GEOMETRY (TOPOLOGY)**	
			STATIONS OBJECTS		**SET OF NODES, VERTICES V**
			TRANSPORTATION LINES		**SET OF EDGES E**
			(GEOGRAPHIC) LOCATIONS		**FUNCTION F: V → M (MAPS NODES IN THE GRAPH TO A SET OF POSITIONS M**
			REAL DISTANCES BETWEEN OBJECTS-DESTINATIONS / STATIONS		**METRIC D, I.E., THERE EXISTS A FUNCTION D: M × M → R+ DEFINING A PAIRWISE DISTANCE BETWEEN ELEMENTS IN M**
			FREQUENCY AND DIRECTIONAL CHOICES		**W: E → R+ ASSOCIATES A WEIGHT WITH EACH EDGE: A POSITIVE REAL-VALUED NUMBER THAT DENOTES ITS CAPACITY**
			NUMBER OF PASSENGERS, OBJECT TYPE, SINGLE OR MULTIMODAL, ETC.		**ADDITIONAL DATA**
02					
PARAMETERS / CONSTRAINTS		**parameters analysis -** selection of the relevant parameters		**constraints**	
			current traffic variables/indicators		traffic parameters (efficiency operation indicators)
			ground properties - suitability, load satisfiability, geotechnical properties		network pattern and length **cost - variable**
			land ownership		network pattern and length - geometry cost - variable
			finances (bank credit approval and other sources)		financial arrangements
			cost/km		cost - **variable**
			built environment/structures constraints induced by them (coverage, foundations, etc.)		network length and pattern cost
			population density		population - **user demand**
			risk assessment		risk assessment (coefficient)
			safety / security		network pattern
			value engineering		
			accessibility (physical, financial, cultural, etc.)		
			zero carbon emission aims		**variable**
			sustainability		
03					
OBJECTIVES		**PARAMETER EVALUATION AND PRIORITIES**		**objectives** or factors selection –necessary for variation and optimisation	
04				π	
EXTERNAL POLICIES / STRATEGIES		**DESIGN AGENDAS**		**policy**	
			NETWORK ROBUSTNESS/RESILIENCE		network robustness/resilience
			NETWORK EFFICIENCY		network efficiency – geometry, dynamics
05					
PROBLEM-RELATED DATA ACQUISITION (ACCORDING TO SELECTED PARAMETERS)		**SOURCES**		**DATA SOURCES – RELIABLE DATA – RELEVANT AND PLAUSIBLE**	

06			
MODEL PARAMETRIZATION		**INPUT OF VALUES AND VISUALISATION**	**PROGRAMMING**
07			
SEQUENTIAL FUNCTIONS PROBES AND METHOD INVESTIGATION		**ALGORITHMIC LOGIC** **COURSE OF DESIGN PROBLEM-SOLVING ACTIONS**	**ALGORITHMS (EXECUTIVE ACTIONS)**
08A		**design problem/branch a**	
PATTERN CONSTRUCTION		**network nodes' connectivities - network optimisation and restructuring**	**NETWORK OPTIMISATION**
		new stations (construction) new destination points	NEW NODES **S** – set of states (**s1, s2, s3, … s_n**) decision points
		new routes (construction) new trajectories	new edges **A(s)** - set of trajectories/actions
		programmatic conversion of stations and destinations – removal from the analysed system	nodes ablation
		programmatic conversion or unusability of trajectories – removal from the system	edges ablation
09A		**DESIGN PROBLEM/BRANCH A**	
GEOMETRY			
08B		**design problem/branch b – b1**	
PATH CONSTRUCTION		**movement path generation (definition of actions within the network)**	**transition**
		definition of possible connectivities	**S** – SET OF STATES (**S1, S2, S3, … SN**) DECISION POINTS
		A(s) - SET OF TRAJECTORIES/ ACTIONS	
		construction of new edges	**A(s)** - SET OF TRAJECTORIES/ACTIONS
path variations action probability - results and visual expression		**network/path variables** **(options and choices)**	**SEARCH SPACE AND PROBABILITY ALGORITHMS**
		grafts/increments – possible directions of path development	**P** - probability distribution (over the legal moves)
		set of all possible destinations from the current location (state)	**St** - set of new states
		number of possible moves/actions/path grafts/ next destination	matrix of weights **W** (weight for move/action A of player p in a state S)
		performance simulation	procedure ***playout*** (Cazenave, 2016; Sironi, Cazenave, and Winands. 2021)
		search (Carpo, 2017 – the *logic of search*)	MCTS (Darvariu, Hailes, Musolesi, 2023; Cazenave, 2022; Roucairol and Cazenave, 2022)
		enabling feedback updates	procedure ***adapt***
		visualisation	**visual programming**
		system geometry and path rendering and animation (simulation)	preview properties/functions of both the procedures and the results of their execution
		design method (graph) visualisation	
		behaviour factors and new feedback directions	***reward*** **(*return*) and rules of their processing (backpropagation)**
			set of rewards **R**
			discount factor γ
			policy (legal moves) including N-**PPA-**MAST
		enabling of the feedback updates	procedure ***adapt*** player policy adaptation (PPA and extended **PPA, MAST, NST, random**)
			the numerical values that the agent receives while performing a certain action at a certain state within the environment (numerical value can be positive or negative based on the agent's action)
		design problem/branch b – b2	
AGENTS		**agents and scenarios definition -** path specification/ customisation	**paths diversification and classes**
		agent classes and attributes	set of agents **Ag (Ag_1, Ag_2, … Ag_n)**
		path classes (criteria definition)	criteria expression - variables
		C_1	
		C_2	
		…	

			narrative, movement procedures		algorithm
		design problem/branch b – b3			
temporal parameters and timelines con-struction		**definition of scenarios and their temporal representation (timelines construction for set of defined actions)**			
		design problem/branch b – b4			
integration		**integration of all decomposed actions into the complete user experience**			
09b		**DESIGN PROBLEM/BRANCH B - CONCLUSION**			

The process tracks each one of them through the following separate stages: 8a (design problem) - definition of network nodes' connectivities/network optimisation and restructuring, 9a (design problem) - conclusion, and 8b1 (design problem) - path construction and variation, search space, and probability (math.), 8b2 (design problem) - inclusion of agents and path specification according to given objectives and criteria, 8b3 (design problem) - inclusion of temporal data and variables, 8b4 (design problem) - integration, and 9b (design problem) - conclusion. As the table suggests, after performing the network mapping and design (spatial environment construction, with respect to topological modalities for both abstract and real-world cases), parameter analysis and specification, data operations, and probes of methods as singular sequences, the problem branches in order to span two important dynamic aspects. The first one (branch a) gives space to network dynamics (possible system/network restructuring and incremental growth, therefore changes to the system of possible moves considered by branch b), while the second (branch b) addresses the movement paths and timelines generation within the defined network, based on the agents' decision-making expressed through parametrisation which guides spatial performance, all visually diagrammatically displayed according to the chosen framework (a set of possible, desired, and legal moves) and individual scenarios (Fig. 1).

Organised in such a way, design problem definition and solution structure (a set of methods) can easily be further transposed to an algorithm and set into the procedural executive mode.

URBAN COMPUTING, PLANNING, ANALYTICS, DESIGN, AND OPERATION METHODOLOGY: SPATIAL PROBLEM DEFINITION AND PARAMETRIC, ALGORITHMIC, AND GENERATIVE SOLUTION FORMULAS

Referring further to the problem of proper interdisciplinary terminology, the following lines will provide a brief preview of terms clustered around *spatial, architectural, and urban computing* regarding planned problem-solving methodology. The focus will not be on the theoretical framework that preceded and defined most of the current practices of spatial planning, analysis, analytics, design, and operation, but rather on their application and recent results of technological development in that respect. Some of the key authors and references may be mentioned so as to situate all similar interdisciplinary efforts in the proper research, scientific, and operable context, with Michael Batty (1990, 1997, 2001, 2005, 2008, 2009, 2018), Bill Hillier (1996), Michael Goodchild (1991, 1992, 2009, 2011), Jorge Gill (2020), and others at the forefront (Abrahart and See, 2014; Batty and Longley, 2014; Serra, Gil and Pinho, 2016; Li, Betty, and Goodchild, 2019; Shi, Goodchild, Batty, Kwan and Zhang, 2021; etc.), while major remarks that address relationships between *artificial intelligence and computer sciences* and *urban and architectural studies* at the methodological level should come as the primary aim regarding generative design problems definition and solutions, as well as data-driven decision support in spatial systems analysis, planning, and design.

Computing, computational methods and techniques – elements of the constructed problem-solving methodology

This section addresses the difference between parametric, algorithmic, and generative design, all representing categories of computational design as a *method of employing programming to design and alter forms and structures* (Kyratsis in Michelle and Gemilang, 2021:30), or, in other situations and more broadly, employing programming to solve design or planning problems, perform design-oriented analyses and predictions, produce innovation, or technologically facilitate design processes.[1] It has been presumed that proper explanation of the stated terms and methods will lead to their better understanding and correct use, especially due to the fact that various inconsistencies have been identified in that respect.

The first register to be singled out relates to **computation, computer sciences, computational thinking, analysis, planning, and design**. Before the topic of computational approaches to spatial design problems has been raised, it is important to underline the entry of computational thinking (CT) into each research area and discipline, including CT teaching, learning activities, and conceptualisation (Angeli and Giannakos, 2020 (2019)). Besides the hands-on application of computational thinking and technologies, it is assumed that proper systematic curricula and professional development programs assist in providing students, teachers, and professionals with the necessary computational competencies and skills that will enable them to qualify for teaching within this area and come up with new ways of computationally framed problem solving, in this case focused on various spatial issues. The latter, considering educational requirements, relates to specialised expertise in computational thinking and design (Caetano, Santos and Leitão, 2019:290). It has been said that computational thinking implies knowledge about 1) *designing computational solutions to problems, algorithmic thinking, and coding* (Angeli and Giannakos, 2020 (2019):1), 2) *use of structured thinking to produce appropriate output to a given input* (Denning in Angeli and Giannakos, 2020 (2019):2), 3) a *process that involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science* (Wing in Angeli and Giannakos, 2020 (2019):2), 4) skills such as *problem decomposition (breaking down complex problems to simpler ones), developing algorithms (step-by-step solution to problems), and abstraction* (Angeli and Giannakos, 2020 (2019):2), as well as 5) the *way of devising computational resolutions to solve problems* (Michelle and Gemilang, 2021:30), or handling (*design*, emphasis added) problems in a “thinking before acting” manner (Papamichael and Protzen in Caetano, Santos and Leitão, 2019:289 Thus, computational thinking competencies and skills, pedagogical strategies, professional development programs, assessments, and qualifications (Angeli and Giannakos, 2020 (2019):6) constitute an integral part of and a precondition for proper application of computational problem-solving and (spatial) problems computing in abstract and real-world contexts. At one of the levels of the paper, there is a proposal on how to design spatial computational tasks and learning activities, and use computational thinking and assets to teach and investigate spatial subjects, having one of the possible areas and problems (urban movement/mobility) probed in closer detail.

As applied to spatial problems’ representation, analysis, and design, or spatial design and problem-solving through computational techniques, methods, and thinking, a more specified definition related to spatial design can be derived from the previous notions. It can be suggested that *spatial computing* indicates the application of computational thinking – thinking in terms of the main concepts of computer sciences, thinking through algorithms, and abstract systematic thinking – to spatial issues; in other words, *spatial computation* involves designing computational ways of modelling, analysis, representation, and resolution of spatial problems – or, devising computational representations, analyses, and designs for spatial problems and devising computational design methods. The required interdisciplinary competencies for these kinds of operations lie in the field between spatial sciences and computer and information/data sciences and technologies.

1 In reference to Michelle and Gemilang explanation of the difference between algorithmic and generative, a smaller remark has to be added regarding recommended revision of their statements.

While reflecting on terms developed around computing, several key papers have paid specific attention to their proper explanation. Caetano, Santos and Leitão (2019) attempt to explain the differences between computational, digital, and algorithmic design. They consider the attribute of being *computational* within the range between the forms of analogue computation (Otto and Rasch, 1996 in Caetano, Santos and Leitão, 2019:289), implying computation that can be employed without digital tools, to forms that are used in examples technologically supported by digital tools and processes, alongside the most recent and advanced digital computational techniques (Caetano, Santos and Leitão, 2019:290). The major objective in computing techniques application lies in their active and transformative power in planning, analysis, and design tasks, some of which have also been defined by Caetano, Santos and Leitã (2019:290), going beyond the mere drafting and automation of representational tasks. We can conclude this part of the terminology overview with computation used for creative purposes - *computational design*. According to the most recent Autodesk *Generative Design Primer*, computational design represents not just any one algorithm, but rather *an approach whereby a designer defines a series of instructions, rules and relationships that precisely identify the steps necessary to achieve a proposed design and its resulting data or geometry* (AEC Generative Design Team, 2020), suggesting that these steps must be computable (understood and calculated by a computer). In other words, the attribute of being *computational* implies a well-planned design process and methodology that maps the precise way from input to output data and objects, expressed in a manner that can be computed (executed by the computer). The lines of code and algorithms are such computer-executable expressions.

The second register narrows down the area of computer sciences and technologies, or computing in general, directing the scope of algorithmic thinking and design (specific instructional expressions for performing aimed operations) towards the field of artificial intelligence, having them in particular applied in spatial, architectural, and urban studies and sciences. We speak about the most recent computational tools and methods of spatial, architectural, and urban research and practice that involve new software plug-ins created to assist in different research, design, planning, and analysis processes, or to optimise and automate their algorithmically organised or described development phases and design procedures. A reference to artificial intelligence specifies the field of computational operations and algorithmic expression and execution in terms of autonomy in performance and intelligence considering the initial idea of automation. The literature to be consulted on this level is broad (Wright Steenson, 2017; Carpo, 2011, 2017; Bava, 2020; etc.), especially the one dedicated to various topics on AI and architectural design (Chaillou, 2019, 2022; Koh, 2020; Picon, 2020; As and Basu, 2021; Del Campo and Leach, 2022; Bernstein, 2022, Del Campo, 2022, Leach, 2022; also in Ćirić, 2022), while, as a consequence of design research and application in practice, and within the field of software development, several AI plug-ins have been released in support of the major architectural objectives (*Spacemaker – Explore* (Leach, 2022:119-124); *Veras* for Sketchup, Revit and Rhinoceros, *ArkoAI* for Rhinoceros; *Dynamics* for BIM and Revit; Grasshopper plug-ins). Their algorithmic composition comprises generative design algorithms, optimization algorithms, world models' simulation algorithms, machine learning algorithmic models, etc. (Christensen in Leach, 2022:123-124). Searching for the best problem-solving operations and methodology, some of them have been planned to be tested in line with the problematised generative design problem and objectives, representing a part of the software survey method. Thinking algorithmically – *knowing in advance the course of the used methods for arriving at the planned output or a design outcome, along with their proper design and organisation (including dynamic adaptation or self-learning as in some forms of artificial intelligence)* – implies the capacity of understanding the inner logic of all actions that lead towards the planned objectives, parameters that shape the process and course of actions, and ability to steer this process accordingly. AI supports such approaches by facilitating and automating the sequences or whole sets of operations within the specific subgroup of intelligent algorithmic thinking.

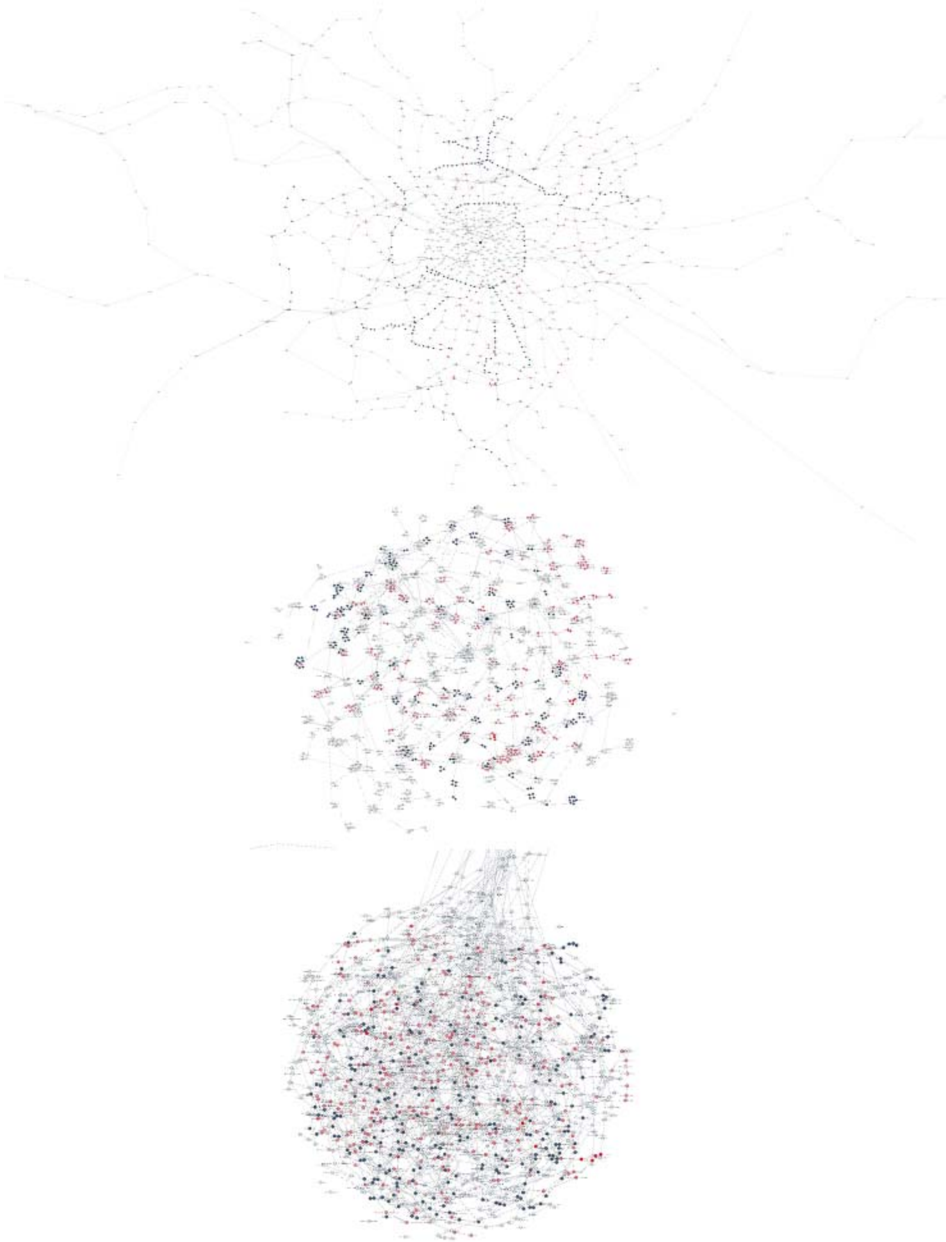

Figure 2: Paris railway transportation system graph (type: undirected graph). Software: Gephi. **2.1.** Geo Layout (each node has been assigned geographic coordinates – longitude and latitude). **2.2.** OpenOrd Layout. **2.3.** Fruchterman-Reingold Layout. Source: © Dragana Ćirić, unit [d], 2023.

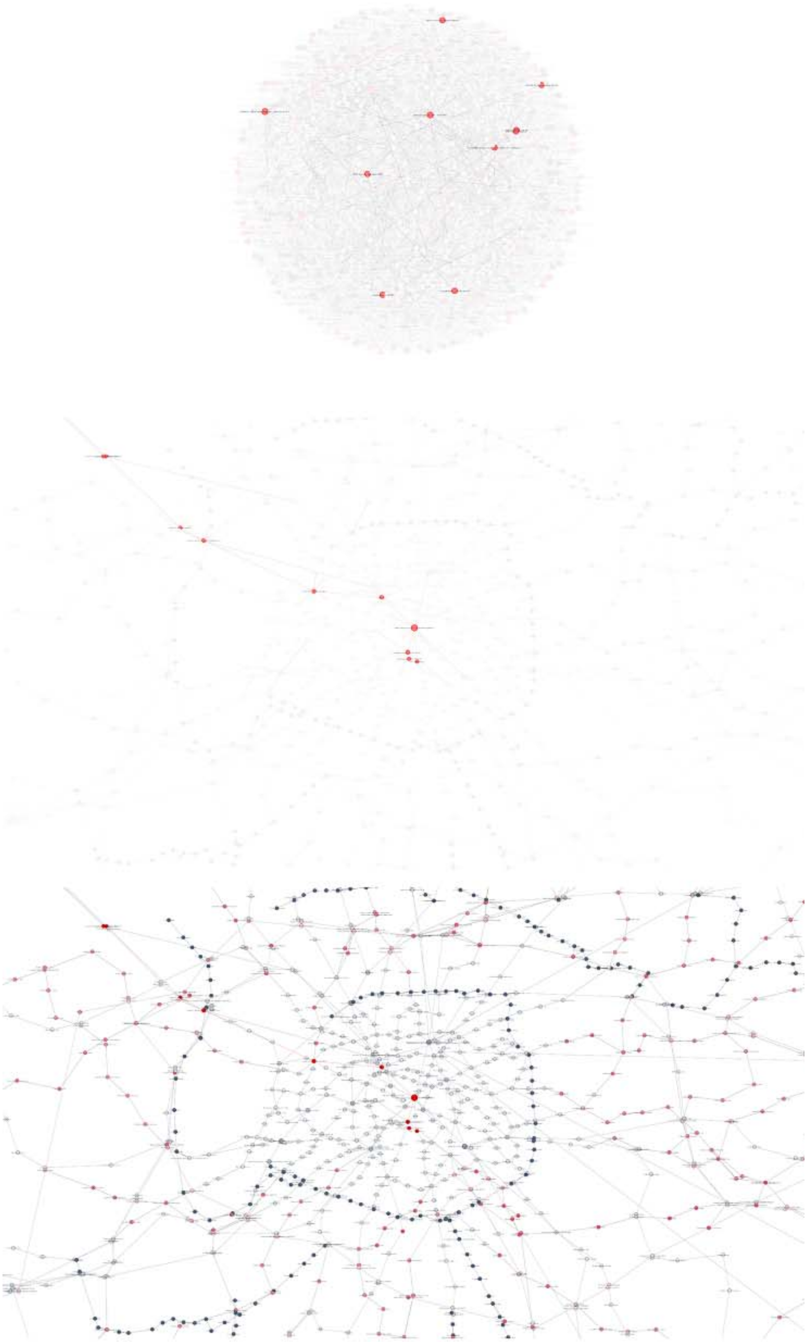

Figure 3. The shortest path between the chosen pair of “origin-destination“ points (in red). Context: Paris railway and metro system network graph. Example: the path between Houilles Carrières sur Seine and Maubert Mutualité. Layout: **3.1.** topological layout, based on abstract relational diagram and geometry, and **3.2.-3.3.** geographic layout, based on real distances and real-world geometry. Software: Gephi. Source: © Dragana Ćirić, unit [d], 2023.

The third register recalls a definition of the generative design problem or the attribute of being *generative*. It is necessary to recognise or devise a generative principle in identified problem or a given task. This represents the last subset of the narrowing that has started from the initial group of computational actions and expressions (indicating that a digital form of generative logic and formula has been targeted due to the fact that generative principles exist outside the digital world, too), framed or assumed to be automated and intelligent when paired with the second, abovementioned intelligence register. Introducing generative design approach to previous computational scopes implies a creation, or definition of the system (program, algorithm, or procedure containing a set of actions or operations) that will generate a solution to the design problem – the output that has been aimed at. This usually includes a certain level of autonomy or automation, as well as a space for creative accidents and unexpected occurrences that broaden the scope of possible, or probable outcomes (Caetano, Santos and Leitão, 2019:294), all based on generative processes and logic. A valuable database of generative design experiments and explorations is certainly the Generative Art Conference repository of papers and performances (Soddu and Colabella, 1998-2022), Grasshopper plug-ins repository (Food4Rhino), the selection of papers and works presented at ACADIA, eCAADe, and CAADRIA conferences, or DMS (Design Modelling Symposium), as well as the reference lists of some of the reviews consulted hereby (Caetano, Santos and Leitão, 2019).

The last group of algorithmic functions that have been applied are based on graph theory (Barabási and Pósfai, 2018), which has provided *an efficient modelling, analysis, and computational method* (Gao, Wu, Siddiqui and Baig in Michelle and Gemilang, 2021:34) *for a broad spectrum of connected systems* (Easttom in Michelle and Gemilang, 2021:34). Graph representations and structures have been widely applied in urban and architectural research and design, but their computable data formats and all possibilities of their usage are, perhaps, less known or less frequently addressed in architectural and urban studies aside from highly specified research with a primary focus on final outcomes of algorithmic performance. For this study, graphs have been applied to define a design environment—an urban mobility network (Fig. 2). Within this system, the planned movement could have been articulated along with an analysis of the network's growth and rearrangement. The analysis of the network dynamics (incremental growth and restructuring) has been defined as a separate design goal and one of the possible branches of design problem development, while the generation of movement paths within this system represented the primary design task (Fig. 3).

CONCLUSION

The study has contributed to collaborative framework for generative design problem definition and solution involving spatial and computational sciences. It has addressed issues of interdisciplinary terminology for spatial computing, design problem definition, and organisation of its development phases, supported by key references and original individual studies and their results. Computational methods of spatial inquiry and thus produced urban intelligence as input for analytical, design, or planning operations have been placed at the central methodological plane of the paper, providing similar design attempts with better insights into fine differences between explained concepts of generative, AI, and graph research and design methods. Referring to latter, the aim has been to imply their application in the areas of urban mobility, agent-based decision-making (Ferraiolo, 2022) and modelling (Batty, 2001), urban experience scenarios construction, urban navigation, movement representation, design, and analysis, and urban informatics focused on networks, infrastructures, transportation and movement modelling. Exemplary generative design problem performed on the Grand Paris railway network and its problem-solving method investigated thus far, illustrated some of the stated theoretical and methodological notions. Alongside operability in a real-world environment, by indicating connections to gaming strategies and simulations (Taylor, 2009), the study has also opened the way to subsequent phases of the project development, the results of which can be expected in the upcoming period. This phase will be tailored as a comparison of the presented collection of knowledge to more advanced and efficient problem-solving frameworks, relying on AI search and optimisation methods designed by experts in the field of computer and data sciences.

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