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Urbanism beyond Cognition: On Design and Machine Learning

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This paper will discuss the relatively recent introduction of Machine Learning algorithms in spatial design. The discussion will be visually supported by some examples of the work developed in the Master in Urban Design at the Bartlett; particularly, projects developed within Research Cluster 14 [RC14] – taught by Roberto Bottazzi and Dr. Tasos Varoudis. Machine Learning [ML] represents a technical sub-field of the larger endeavour of developing Artificial Intelligence [AI]. Nevertheless, ML is still a broad area of research which will be further narrowed down in this paper to the use of statistical methods in design. The algorithms discussed in the paper are: K-Means Clustering, Principal Component Analysis [PCA], and t-Distributed Stochastic Neighbour Embedding [t-SNE] algorithms.[1] The objective is to expand the conversation on these algorithmic procedures to foreground what is at stake when applied to design, what kind of spatiality they could engender, and, consequently what relations between society, space, and computational technologies one could imagine. Design is here mainly understood as a problem of distribution; the task of the designer could be said to be that of organising and managing a series of objects, bodies, and data within a physical territory. Defined as such, the design process aligns well with the statistical methods deployed by Machine Learning algorithms and it provides a common platform through which transfer notions and share theoretical preoccupations. The structure of the paper is broadly divided into two parts: the first one will provide the conceptual foundations to the discussion by retracing some of the key steps and ideas which guided the development of learning algorithms, whereas the second part will describe how algorithmic procedures can be deployed and reflect on their relevance within the field of urban design.

It could be argued that the introduction of new technologies always shifts the epistemological horizon of the different fields they impact on. New instruments allow to expand the range of parameters shaping a discipline’s working methods which in turn change its very purview and impact. Design is no exception in this narrative, whether we take this statement in its general or literally meaning, we can always see how design and technology interact and affect each other. The development of lenses impacted the science of the seventeenth century allowing scientists to explore scales of matter both far smaller and larger than anything had been empirically experienced before which, in turn, changed the methods of scientific inquiry. At around the same time, Baroque architecture was also influenced by these transformations and began to expand its formal repertoire to include spirals and ellipses; that is, geometrical figures characterised by a certain ‘instability’: ellipses have two centres, whereas spirals endlessly coil towards the infinitely large and small.

More poignantly for our conversation is the role of technologies to gather data played in the work of Buckminster Fuller. Starting as early as 1917, Fuller had been recording every single activity or occurrence in his life forming a collection of documents that amounted to “…737 volumes, each

[1] For a general overview of these algorithms and statistical methods see: https://en.wikipedia.org/wiki/K-means_clustering, https://en.wikipedia.org/wiki/Principal_component_analysis, and https://lvdmaaten.github.io/tsne/. (Accessed January 22, 2019).

containing 300-400 pages, or about 260,000 letters in all".[2] The organisation of personal notes, sketches, or even utility bills, but also numerous paper clippings of relevant articles, charts, and articles written by others on himself (approximately over 37,000 in 1980) allowed Fuller to construct an 'objective' tool to observe his life from without in order to detect larger patterns of societal and technological transformation he could not have possibly fully perceived at the time of their actual occurrence. The subsequent work for the development of the *World Game* clearly emerged as a result of the new perspective acquired. In its first incarnation in the form of a series of inventories of world resources, the *World Game* immediately presented itself through a great expansion in the scale and timeframe of design. The maps and diagrams implicitly illustrated a different framing of design now operating at much larger scales and timeframes: many charts describe the evolution of phenomena since the beginning of civilisation and/or at planetary scale.[3] It is only by considering the importance of data that it is possible to understand the innovations introduced by design projects such as the *Geoscope* and the actual *World Game*. Their innovative qualities lie in their capacity to synthetise and expand through design means ideas first emerged from advancements in data collection, managing, and visualisation.

These issues are not only still present today but they have further been complicated by a series of cultural and technological innovations. On the one hand the explosion of the data gathering, sorting, and mining techniques has provided new and exciting opportunities for design. As this paper articulates, this research has now expanded to include AI whose definition is here restricted to a particular class of algorithms [Machine Learning] to analyse very large datasets. The characteristics of such algorithms challenges established narratives on the role of digital tools in design. On the one hand, the idea that digital technologies are mere helpers, or "perfect slaves", as Coons[4] put it. Though this idea acknowledges the interaction between software and user, the former is merely employed in order to increase efficiency. Though we cannot discount the importance of streamlining the design process, the creative act underpinning design is fundamentally not just about efficiencies, but rather a more complex synthetic process in which many cultural, societal, and technological concerns merge in a metastable balance. The interest in ML algorithms is therefore not to just reinforce the quest for efficiency and optimisation but rather to exploit the possibilities engendered by such algorithms to map out the design space beyond the traditional parameters considered in the design process, challenge traditional design habits, and speculate on their larger impact on disciplinary and cultural concerns. On the other, the increased automation of the design process has invited to dismiss theoretical analysis in favour of 'letting the data speak'. In an article published in 2008 in *Wired* magazine, editor Chris Anderson labelled this new paradigm "The end of theory".[5] Anderson's argument only strengthens with the coupling of ML algorithms and large datasets. However, the risk is to uncritically embrace these new technologies: in urban design, for instance, the promise is that by amassing data, parsing them through algorithms, one might generate entire designs bypassing any historical or disciplinary concerns. In this scenario only a greater, more

[2] Fuller, R. B. (1981). *Critical Path*. New York: St. Martin's Press. p. 134.
[3] Fuller, R. B. and McHale, J. (1965) *World Design Science Decade 1965 – 1975: Phase 1 - Document 4: The Ten Year Program*. Carbondale: Southern Illinois University, World Resources Inventory.

[4] Coons, S. A. (1963). "An Outline of the Requirements for a Computer-Aided Design System". *In Spring Joint Conference*, Detroit, Michigan. New York: ACM, p. 301. Quoted in Cardoso, D. L. (2012). *Builders of the Vision: Technology and the imagination of design*, Ph.D Thesis, MIT, pp. 49-50.

[5] Anderson, C. (2008). "The End of Theory: The Data Deluge Makes the Scientific Method Obsolete" [online]. Available at: http://www.wired.com/2008/06/pb-theory/ [Accessed on August 20, 2019].

complex theoretical and historical framework – rather than its abdication – would enable us to discuss the work.

It is also equally clear that the impact of these issues goes well behind their theoretical nature. Larger aspects of our infrastructures and production systems are increasingly automated; a tendency that is predicted to become more prominent in the future changing the nature of cognitive as well as physical tasks. Likewise, climate change calls for an approach to design in which conventional scales of thinking and, possibly, intervention will be challenged. Here too, technologies for data mining play an important role not only because of the vast amounts of energy required to propel computers, but also because their essential to make visible climate change and therefore an object of design inquiry. These are the aspects we ought to concentrate our design and speculative efforts in order to move the conversation behind pure functionalism to embrace a more complex and richer set of issues. Theory and history of such automation and the technologies to manipulate data are essential ingredients to begin to stir the conversation beyond mere efficiency.

Computation, AI, and Machine Learning

To grasp what is at stake in the use of ML for design, it is useful to briefly trace the ideas that accompanied the emergence of the field of Artificial Intelligence. The first explicit definition of AI in the age of modern digital computers is traditionally made to coincide with the organisation of the Summer Research Project at Dartmouth College in New Hampshire in 1956. The original proposal for the project – signed by eminent American scientists John McCarthy, Marvin Minsky, Nathaniel Rochester, and Claude Shannon in 1955 – not only sketches the boundaries of the discipline, but also makes a series of important distinctions that have shaped the debate since and still have traction in articulating the conversation on algorithmic intelligence in contemporary design. Broadly speaking these two positions can be categorised as: a bottom-up approach based on strong procedural rigour which yielded high theoretical results but little practical success [a position that dominated the research on AI throughout the 1960's] and what we could term as a data approach, less emphatic vis-à-vis theoretical claims in favour of a more performative, statistical approach seeking whose results have been significantly more convincing than anything achieved in the 1960's. This latter tendency only emerged in this century and is still dominating the debate on AI through Machine Learning.

First, it is important to draw the attention to the definition of AI provided by the four scientists which is still accepted as a main cornerstone in the field: "… For the present purpose the artificial intelligence problem is taken to be that of making a machine behave in ways that would be called intelligent if a human were so behaving."[6] Such definition does echo that of Turing's paper on intelligence[7] whose contribution would have been essential in shaping this field. Finally, we should also note in passing that Turing's contribution should be considered as part of broader philosophical investigations into the nature of being human which have always complemented the discussion on automata. Turing's own views were in fact mindful Descartes' arguments on machines formulated in the seventeenth century. Later on in the short document, the authors also individuate the bottom-up approach drawn from linguistics and cognitive sciences of the time a necessary step towards the construction of AI: "…Human thought consists of manipulating words according to rules of reasoning

[6] J. McCarthy, M. L. Minsky, N. Rochester, C. E. Shannon (1955). *A Proposal for the Dartmouth Summer Research Project on Artificial lntelligence.* Republished in *AI Magazine*, Volume 27, No. 4, pp. 12.
[7] A. M. Turing (1950) *Computing Machinery and Intelligence*. Mind 49, pp. 433-460.

and rules of conjecture".[8] In order to develop intelligence by artificial means, the advice is to start from the lowest structural point by identifying a taxonomy of elements from which complexity will emerge through combinatorial rules: from more complex compounds of signs signification and eventually meaning will finally arise. The model is predicated on the rigorous definition of the process of thinking through an accurate and valid computational representation of human cognition. We should note that the Turing test did not focus on the actual cognitive mechanisms at work in the brain but rather on its effects. It is by now well known that such approach to defining AI did not produce the results initially envisioned: the emphasis on process did not bode well with the sheer size and complexity of the subject to represent. These efforts were however crucial in prompting more research on AI and eliciting significant theoretical work which problematized important issues including that of defining what human intelligence is.

It was the definition of artificial intelligence mentioned above to prove more successful and resilient. Such definition inverts the focus to shift it to the actual outcomes: for every successful output, the test will not offer clear explanations as to why and how this was the case. This is very much the character and strength of current successes in ML in which stochastic correlation methods, fed by ever-growing datasets, achieve excellent results in, for instance, classifying objects without necessarily replicating how the human brain would perform the same task. AI went performative and not cognitive, a consideration that we ought to keep in mind when thinking about how Machine Learning algorithms have an agency on design. From a conceptual point of view these algorithms are of great interest not so much because of their efficiencies, but rather because they offer alien modes of 'thinking' which may incidentally shine some light on how cognition works, but, most importantly, because they can inform a different type of spatial organisation underpinning design.

The creative and intellectual implications of such approach are profound and can be foregrounded through a quick overview of the first practical attempt to use statistical means to classify and even understand a complex set of signs such as the one presented by a written text. Andrei Markov's mathematical analysis of language opened up the performative approach we can still see in ML. In 1913 the Russian mathematician presented an analysis of Pushkin's work based on statistical methods rather than traditional literary criticism. By sampling the text into blocks of 100 words each, Markov counted the letters' distribution and statistically began to highlight patterns [e.g. number and position of vowels and consonants] and deviances which allowed him to operate the first mathematical treatment of language.[9] Some crucial points for architects and designers immediately emerge from this experiment: the emphasis of the analysis is not on the individual letters [the constitutive elements] but rather on relations, these are in turn only treated statistically allowing for knowledge on the text (the detection of patterns or random elements) to emerge without simplifying it. Finally, a different image of the text is obtained through pure operations of mathematical rewriting [from letters to numbers] and, most directly related to current ML algorithms, partial understanding knowledge of the text can be obtained without any prior knowledge of it and without engaging in its semantics.

[8] J. McCarthy, M. L. Minsky, N. Rochester,C. E. Shannon (1955). p. 14.

[9] Link, D. (2016). *Archaeology of Algorithmic Artefacts*. Minneapolis: Univocal. pp. 29-54.

Design with learning algorithms

These historical conversation can not only inform but also take a new meaning when we consider the current landscape of design. On the one hand, the emergence of fully automated spaces such as those or large distribution centres or factories shifts one more time the relation between signs, machines, and space. As mentioned above, despite the complexity of such spaces, we are still largely confronted with attempts to streamline and optimise a series of functional operations. Markov's work therefore represents an important precedent not only because it is still widely employed on websites to direct customers' choices, but also because it does away with the artificial division between quantitative and qualitative aspects of data, therefore expanding numerical and logical operations to acquire design agency. This is after all the same path which transformed CAD from a mere technical tool to improve precision, speed, etc. to eventually engender a new kind of design both in terms of the formal outcomes and procedures. The "nonproportional and electronic"[10] nature of digital data should be exploited to expand the remit of design encompassing domains previously inaccessible. Data can represent scales that far exceed that tackled by designers and so do the algorithmic means to engage it: gathered on a planetary level, with higher precision and potentially updated in real time, digital data allows to speculate beyond received notion of scale, type, function, and temporality.

The work presented here has been developed by Research Cluster 14 in the Master of Urban Design at the Bartlett, UCL in London. Within the cluster large datasets about immaterial elements of urban life such as environmental and experiential factors are utilised to complement the design of parts of London. ML algorithms are utilised to extract patterns from the data gathered in order for non-human elements of city fabric such as pollution, sound, etc. to have a stake in the design process. The aim is to expand the domain of urban design by widening the range of scale of intervention: from the minuscule to the potentially global. ML algorithms not only allow to crunch large datasets, but they can also return a very different image of the city; one that could have not been appreciated by human senses or cognition. One of the key issues in this process is the relation between the use of algorithms for analysis and their role in affecting formal, material, and programmatic decisions. The following are some considerations on the opportunities and issues emerging from working with the 'alien' logic of ML.

Similar to Markov's experiment, working with large dataset also offers the possibility to engage large datasets in their entirety, without fragmentation. Markov only limited his analysis to groups of 100 words because of practical reasons; however, the methods itself is scale independent and can be used to remap entire datasets without going through gradual incremental steps. Similarly the projects illustrated here exploit the possibility to correlate and interact with several layers of data. Algorithms such as PCA – first introduced in 1901 – allow to statistically reduce the dimensionality of the data and visualise it for human consumption by, for instance, using t-SNE algorithms. The way in which geo-reference data is remapped by such algorithm is key to begin to understand the different spatiality emerging from conflating learning algorithms and design. Contrary to the design methodologies and paradigms which have been informing architectural and urban discussions since the 1960's, linear spatial hierarchies no longer hold to account for algorithmic description of space. T-SNE algorithms visualise correlations in the data in an abstract space; here the dimensions of the dataset rather than its geo-location are to determine the formation of clusters of metastable values. What may have been consistent and continuous in the geographical representation may not be in the algorithmic one and vice versa. Accepted spatial

[10] Hayles, K. (1993). *Virtual Bodies and Flickering Signifiers*. In *October*, Vol. 66, autumn issue, pp. 69-91.

approaches to compression of spatial data, such as bottom-up and top-down, may no longer adequately represent the distribution of data as statistically remapped. Statistical approaches allow to analyse data in a more open, less prescriptive fashion which allows to foreground more complex modes of distribution including granularity, potential jumps, connections, and correlations as these can be all preserved. The type of patterns returned by algorithmically mining large datasets are move between the granularity of the individual data point to the whole set. Therefore they are no longer a priori reducible to Euclidean or even topological spatial models of representations: clustering of similar data can be punctual or extensive; distribution of patterns not only escapes linear hierarchies, but becomes the expression of the logic of digital computation (fig.1). This in turns calls for the development of a design language able absorb and exploit such variety and potential discontinuity in the design. The translation of these statistical patterns into massing diagrams is articulated by deploying a granular design languages: presenting higher degree of diversification and, most importantly, being more apt to absorb discontinuities in the data analysis, several projects develop an open syntax of elements that can be used to remap the algorithmic representations of data generated through t-SNE algorithms (Fig. 2 and 3).

ML-driven design also exceeds the models proposed by coupling biology and design or parametrics. Parametrics presupposes the identification of an ideal object or condition – no matter whether present or not – to seed out a whole series of instances all related by continuous variation. Its formal expression has often been associated to that of the field, a distributed system. The emergence of field conditions in architecture accompanied the so-called first turn in digital design and was pitched in opposition to object-based organisational modes.[11] By operating through statistical distributions and correlations, both models are only partially useful as each proposes an overarching spatial organisation which cannot account for the discontinuities, ruptures in scale as represented by, for instance, t-SNE algorithms. Perhaps more accurate in translating statistical distributions into spatial and programmatic organisations are operations of rewriting [another term borrowed from mathematics] or, more aptly for design, nesting which allow for spatial and scalar inconsistencies whilst remaining logically coherent. Rewriting is no longer relying on ideals situated in a transcendental domain but it exploits patterns and randomness within the bounds if its own dataset. For this reason, a more granular, fragments design language offers richer variety to rewrite the various datasets with: more articulated and nested with more variations, this approach opens to a different aesthetics no longer seeking smooth and continuous morphologies. (Fig. 4)

The divergence from the biological model needs to be qualified further. It is not the emphasis on adaptation to be superseded here (on the contrary, as we shall see, this is not only an important element, but also very much an open question), rather the particular way in which biological models and computational ones merged. This has mostly presupposed to move from the particular to the general: Cellular Automata [CA] is perhaps the most successful computational method to simulate growth and evolution in biological and physical systems. Based on simple initial conditions and rules, through a recursive calculations it can grow into complex formations. The process alludes to a certain predetermined spatial hierarchy which starts from the smallest set (of elements and rules) to propagate to larger domains. This is fundamentally different from the methods exposed here. At any point in time a dataset is always mined by algorithms as a whole and, from the point of view of computational logic, cannot be broken down into smaller components.

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[11] Allen, S. (1999). *Points + Lines: Diagrams and Projects for the City*. New York: Princeton Architectural Press, pp. 90-103. Carpo, M., edited by (2013). *The First Digital Turn in Architecture 1992-2012*. Chichester: Wiley Press.

Statistical approaches to data allow to interrogate it in its entirety, working with its original complexity avoiding reductions in either the size or dimensionality of the data. The role of algorithms here could be compared to that of plans and sections in conventional orthographic representations of space: each algorithm 'slices' a body of data returning a certain image of what interrogated; in the case of learning algorithm this image is also highly dependent on the parameters describing the algorithm itself. Datascapes are however given 'all at once', not as parts and they can only be treated at the very scale they exist at. (Fig. 5)

Though most databases used in urban design are relational, this is still a fundamentally static technology. In order to work within the constrains imposed by the architecture of computation, at any given moment in time a database must unambiguously determine the number of items in it and their individual value. If databases are dynamic, this can only be assumed to happen in a discrete fashion. How to relate the temporality of databases to design still remains an open question requiring more experimentation. However, it is already clear that large datasets allow to operate on spatial qualities that exceed that of pure formal manipulations to embrace softer, more perceptual aspects of space.

Conclusions

This paper aims at accompanying the introduction of ML algorithms in design by problematizing a series of historical and disciplinary issues. History is useful in so far as it helps unravelling the long development of technologies to simulate human cognition and heighten our awareness of them. Likewise, a critical reflection on the design agency of statistical approach to urban problems can help develop original work. Both issues stand against certain trends in the field. First, one could fall trap of a pseudo-scientific approach in which the conflation of data and algorithms become self-fulfilling in their goals: as long as a valid set of data is provided, an algorithm will always a return a result coherent to itself. Such uncritical take on technology calls for more, deeper connections between technology, society, and philosophy. Similarly, ML algorithms should not simply be employed for optimisation, but rather to problematize design operations by scoping out a wider range of options. Such augmented design agency is also essential to fully integrate urban elements which affect our life but may not be directly perceived such as climate change.

Beyond optimisation, statistical approaches offer an insight into alien ways of thinking the city: ML algorithms may reach solutions that we can appreciate but they may do so in ways that are different from our own. The challenge here is to be able to critically evaluate the outcomes attained through ML beyond their aesthetic dimension. Referring back to the mathematical and philosophical conversations that accompanied the evolution of these algorithms will be essential. Finally, as in the case of Baroque architecture or Fuller, what is at stake in these innovations is the possibility to evolve the scope and modalities of design. Although research in this field is only at the very beginning the potential for a radical rethinking of how we intervene and use our cities is already detectable.

CAPTIONS

Fig. 1 – 01_tsne.tif – Perceptive Landscapes [Apostolos Apostolopoulos, Caitlin Brock, Anna Kampani] Data clustering: geo-located representation of data point and t-SNE visualisation on the left.

Fig. 2 – 03_wind.tiff – Wind Tower [Chuanren Lin, Lei Wang, Qiuyang Zhang, Xi Meng] Morphological and material studies for a residential tower whose skin generates energy.

Fig. 3 – 04_pollution.tiff – Deprived Landscape [Xinyi Li , Vasileia Panagiotopoulou, Ziyi Yang] Visualisation of statistical analysis based on PCA algorithm.

Fig. 4 – 02_rewriting.tif – Examples of formal studies generated by rewriting datasets through geometrical elements. [RC14 2018/19 group].

Fig. 5 – 05_sound.tiff – Soundscape [Yu Han, Xiaoben Li, Peng Zhou, Guang Yang] Physical model of a proposal for a public space organised around sound.