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Title:

Knowledge by other means: Machinic Duration and Anexactitude in data-driven urban drawing

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Abstract (28 words):

An epistemological exploration of data-driven urban drawing processes as carried out by a custom-built robotic apparatus, identifying non-computable elements of thought in the development of spatialized digital intelligence.

Biography (50 words):

Dr Miguel Paredes is a Lecturer (University of Edinburgh), a chartered architect and a partner in award-winning studio Cuartoymitad Architecture & Landscape. His research is articulated through both writing and speculative practice, operating at the intersection of digital technologies, urban public space and the critical theories of New Materialism.

Word count: 7467 (main text) + notes

Web Abstract (300 words):

Half a decade past the consolidation of the first 'Digital Turn' in architecture, contemporary designers seem to have decidedly embraced the unprecedented power of machinic thinking, subsequently adopting its embedded logical processes. We may, however, pose a critical question in the context of this 'second computational turn': Are there any non-computable elements of thought in the development of spatialized digital intelligence?

As a partial response, this paper unpacks a series of productive relationships intersecting urban drawing and the passing of time in the context of a data-driven design environment. This enquiry looks into the processes carried out by a custom-built robotic drawing machine, tracing dynamic vector data streams collated from fieldwork developed via GPS tracking of individual urban displacements in Cagliari, Sardinia during April 2017. Its machinic drawing protocol re-enacts this continuous, heterogeneous, collectively constructed urban landscape as it slowly remaps its territorial occupation into the target surface of the paper.

The hybrid digital-analogue apparatus draws from a long historical lineage of vector-based machinic systems designed for architectural drafting. Situating themselves between the human hand and the surface of the paper, those machines acted as carriers of embodied spatial knowledge that could be selectively actualised into specific design processes and materialisations.

Deploying a range of intertwined digital and analogue media, this machinic environment is used to articulate a data-based urban drawing research practice and a subsequent 'anexact' drawing research methodology that further elaborates on the durational and multiplicitous aspects of the data-based drawings. This body of work is also reflected on as a visual research methodology, which taps into Bernard Cache's interest in architectural computation as a way to pursue philosophical knowledge 'by other means' and into Gilbert Simondon's notion of the 'technical ensemble' – emphasising the productive forms of indetermination emerging from its internal informational transfers-

Knowledge by other means: Machinic Duration and Anexactitude in data-driven urban drawing

1. Introduction: A contemporary computational episteme

This paper puts forward a series of productive transferences between urban-architectural drawing and philosophical thinking in the context of a digital, robotic design environment, focusing on how the former can be mobilised to construct embodiments of the latter. In doing so, the action of drawing is posed as an active production of knowledge, as opposed to a simple representation of it.

Such an approach taps into Bernard Cache's seminal text 'Objectile: The pursuit of philosophy by other means?' In this essay from 1999, Cache referred to philosophy not as a contemplative activity, but rather as a mode of production –“a calculation of reason and forms”- that had the potential to defy established productive paradigms.¹ Drawing from Cache, this paper argues that architecture (and architectural drawing) constitute the *other means* through which philosophy can be engaged as a mode of production. Thus, a first research question tackles how such a form of engagement can be orchestrated or, in other words, how thinking can be conducted by architectural means. A second question revolves around what is revealed in that process –that is, what kind of knowledge is produced?

In this paper, as well as in Cache's work, both questions are addressed through the combined productive frameworks of digital computation and robotic fabrication. In terms of productive potential, it is obvious that the numerical calculations on which both frameworks are grounded are facilitated by the processing capabilities of contemporary technologies. However, it is also fair to question whether machinic thinking is actually restricted to these algorithmic processes and whether, as a consequence, it is solely dependent on pure computing power.² In other words: Is there a non-computable element of thought in this productive framework? And, how could this component be revealed?

2. *System speaks to System: Robotic technical ensembles*

The unpacking of the questions above starts with a description of the digital, robotic design environment, which we are posing as the epistemological locus of productive knowledge in the context of this paper. We will explicitly refer to it as an ‘environment’ in order to emphasise its plurality. In line with philosopher Gilbert Simondon’s taxonomy of technical devices this environment is not a singular ‘technical object’, but a ‘technical ensemble’ constituted by multiple machinic systems that transfer information from one onto another. Simondon studied the ontological configuration of technological systems, both in relation to human beings and to other systems. One of his most important insights is that information within a technical ensemble is shifted, modulated and translated from one technical object to another. In that process, and drawing a direct relationship to pre- and post-Second World War theories on signal preservation,³ information transferences become inflected by a certain degree of indetermination.⁴ As Bernard Stiegler notes, Simondon framed this ontological account in the context of changing relationships between humans and technological apparatuses from the Industrial Revolution until the beginning of the 20th century, paying especial attention to their competing for the status of “technical individual”.⁵

The technical ensemble presented in this paper can be best described as a drawing apparatus, originally developed to physically enact geometric operations underpinning the development of digital architectural drawings. In this particular technical ensemble ‘drawing’ is understood as a dynamic action: something that develops over time, gradually unfolding *in front of us*. Following Simondon’s taxonomy,⁶ the original source of information to be processed through this particular technical ensemble consists of digital drawings developed using CAD software. As elaborated further throughout the next section, this hybrid digital-analogue apparatus draws from a long historical lineage of machinic systems for the production of architecture. Situating themselves between the human hand and the surface of the paper, these machines were never intended to act solely as drawing aids but, more fundamentally, as carriers of embodied spatial knowledge that could be actualised into specific design processes and materialisations. Throughout their evolution from the mechanical to the computational, the action of physical drafting gradually became a fully robotic endeavour, whereby the agency of drawing eventually shifted from the human hand and eye to procedural protocols executing a systematised sequence of commands. Acknowledging that this lineage can be regarded as an *épistémè* (following Foucault’s understanding of the term as a historically established plateau of possibilities),⁷ this paper traces the ways in which knowledge was historically embedded, as a first step to explore the new epistemological conditions posed by the data-based machinic environment. We refer to this embedding operation as *encapsulation*. This

term is borrowed from Andrew J. Witt's account of the evolution of geometrical drawing aids,⁸ which in turn is predicated on Benjamin Aranda and Chris Lasch's description of a "packaging of logic that allows (...) procedural thinking to migrate inside and through various syntaxes".⁹ *Encapsulation* also taps into Nick Montfort and Ian Bogost's work on low-level explorations of digital media, which they refer to as "platform studies". There, *encapsulation* qualifies both *what* is packaged as a component of a given procedural logic, and *how* it is technically packaged.¹⁰

3. From the mechanical arm to the robotic vector plotter

The potential for incorporating machinic components into architectural thinking can be traced back as far as Vitruvius. For the author of *De Architectura*, the development of ballistic war machines was an architectural endeavour. It was precisely his involvement in that particular line of work that led him to articulate his own theory of proportions as a tool to control the geometry of projectile trajectories.¹¹ In doing so, it can be argued that Vitruvius was already encapsulating geometric design knowledge into machinic protocols at this early stage of architectural thinking. Such practical interest in the instrumental aspects of spatial practice –akin to Vitruvius'– seems to have pervaded throughout Classical Antiquity and the Middle Ages, especially in relation to the realisation of major built works like temples, churches or cathedrals. This hands-on form of instrumental knowledge was primarily based on oral transmission within groups of masons-builders, organised into guilds and operating directly on site.¹² Other more explicit and comprehensively documented instances of architectural engagement with machinic devices did not emerge until the period of the Italian Renaissance. Machinic spatial production is exemplified in the works of Filippo Brunelleschi and Leon Battista Alberti, albeit from markedly diverging perspectives. Whereas the former championed the extension of architectural knowledge towards the instruments that were employed to physically construct a building,¹³ the latter was more interested in the mechanics of the apparatuses that allowed for both the control of representation and its subsequent replication.¹⁴ We can identify Alberti's approach as a preceding branch within the machinic lineage, which this paper is attempting to draw from. Critically, in Alberti's textual description of a machine operating with polar coordinates to graphically reconstruct the plan of Rome we already see the notion of 'plotting' emerge as both a manifestation of encapsulated geometrical intelligence, and a modality of mechanical reproduction.¹⁵

Moving forward in time, the work of eighteenth-century mathematician Giambattista Suardi constitutes the next significant milestone in the lineage of mechanically-driven geometrical plotting. In his 1752 book, entitled 'Nuovi istromenti per la descrizione di diverse curve antiche e moderne,'

Suardi described a predecessor of contemporary ellipsographs enabling the mechanical tracing of an unprecedented range of curves¹⁶. Interestingly, in his introduction of Suardi's work to an English-speaking audience, mathematical instrument maker George Adams referred to this machine as a "geometric pen,"¹⁷ thus reinforcing the linkage between encapsulated forms of geometry and mechanical forms of representation and reproduction. In Suardi's drawing apparatus we can already ascertain the fundamental configuration of modern vector plotters and contemporary robotic devices, defined as a mechanical arm holding a pen (or any other otherwise manually operated instrument) that moves according to geometrically embedded degrees of freedom.

The appearance of a machinic element operating as an interface between the human agency of the draftsman and the physical surface of the drawing was gradually consolidated throughout the 19th century. This was due to the acceleration of scientific knowledge in the fields of mathematics and geometry, coupled with an increased exactitude and scalability in machine reproduction technologies. The result was an unprecedented development of mechanical drafting instruments, which in turn incorporated increasingly sophisticated instances of embedded geometric knowledge, allowing for both the drafting of complex forms and their efficient repetition.¹⁸ As industrialised processes gradually became commonplace throughout the Second Industrial Revolution (the period conventionally situated between the end of the 19th and the beginning of the 20th centuries) an increased demand for reproducible modalities of representation emerged in the fields of architecture and its related domains of spatial practice.¹⁹ On the one hand, this need was addressed through the development of large scale photo-reproductive processes, allowing for the efficient duplication of hand-made drawings.²⁰ On the other hand, the emergence of electromechanical computation at the turn of the 20th century brought about an approach to reproduction that was directly linked to the pre-industrial lineage of machinic encapsulations of geometry described above.²¹ As computerised graphic representations gradually became a tangible reality – especially after the technological boost fostered by the military endeavours of the Second World War²² - the embedded geometrical intelligence of 19th century drafting machines was redeployed into electromechanical apparatuses that operated through computational logic. At that point in time the action of physical drafting became a fully robotic endeavour: the pen plotter arm replaced the human hand in the production of architectural drawings and, equally importantly, the locus of control in the action of drafting was shifted from human hand and eye to procedural protocols executing a systematised sequence of commands.²³

This was the particular context in which the work of the pioneers of computer arts of the 1960s should be considered, collectively leading to a corpus of robotic drawing practices that set the grounds for many of the algorithmic-robotic methodologies of spatial speculation of our present

day. Perhaps one of the earliest examples of such practices, and a testament to the link between robotic plotting and military computational technologies, is the work of academic Desmond Paul Henry at the University of Manchester. Henry developed a series of interactive drawing machines based on heavily modified analogue bombsight computers from World War Two, one of which was featured in the seminal I.C.A.'s 1968 Cybernetic Serendipity exhibition.²⁴ Henry's first machine, built in 1960, can be regarded as a bridge between the analogue drawing apparatuses of the 19th century and the fully digital drafting equipment that started to become commercially available in the early 1960s.²⁵ These primitive commercial plotting suites were also fertile ground for the exploration of drawing, as exemplified in the works of artists Vera Molnár (in France), Colette & Charles Bangert (in the United States)²⁶ and Manfred Mohr (in Germany).²⁷ Henry's machines were based on live interaction with a human operator –thus articulating what was effectively a single-step drawing process. However the aforementioned artists fully embraced a two-step workflow, which became increasingly pervasive in commercial software and hardware throughout the 1960's. This consisted of firstly programming an algorithmic sequence, then executing it through the motions of the pen plotter. It should be noted that some commercial plotting solutions, primarily focused on duplication, were still grounded on live operation by a trained draftsman. An example of this approach is the coordinatograph, which recorded and stored all the mechanical movements executed by the draftsman during an initial 'live' drawing session, subsequently allowing for the retrieval and automated step-by-step reproduction of the recorded sequence.²⁸

Regardless of their electromechanical configurations, a critical characteristic of these twentieth-century computational pen drawing instruments is the fact that they all constitute vector-based systems. From a geometrical point of view, this means that lines and curves are drawn as the visible trajectories of moving points. From an operational perspective, it means that information regarding curves and lines is stored (either mechanically as encapsulated geometry, or digitally as sets of instructions) and subsequently retrieved in the form of sequenced displacements of the pen plotter arm between positions in space.²⁹ Vector-based systems are strictly restricted to the production of linear geometries. Modern digital raster-based systems such as inkjet technology and laser printing (which have become prevalent in all aspects of print production since the end of the 1980s)³⁰ operate by breaking down a drawing or image into a discrete, organised array of pixels. This is reproduced sequentially as an incremental series of rows, which approximates to the actual configuration of the original input (much like the modern standard for the transmission of televised images).³¹

The prevalence of raster-based printing systems over electromechanical pen plotters from the 1990s onwards gradually shifted the focus away from the underlying logical mechanisms established by

earlier drafting conventions, which in turn were originally derived from the mechanical rationale and the embedded geometries of their corresponding drawing instruments.³² In contrast to this, the robotic apparatus presented in this paper draws a connection to the rich historical lineage of vector-based machinic systems, posing that their methodological, operational and material qualities provide a productive framework for an enquiry into philosophical knowledge that is grounded on architectural drawing. In doing so, this robotic drawing apparatus can be linked forward with more sophisticated, contemporary robotic technologies for digital fabrication.

Building a contemporary robotic drafting apparatus from scratch entails gaining an in-depth understanding of both the embedded forms of geometric knowledge which it is meant to deploy, and the different modes of information transfer involved in the translation of digital data into a physical drawing. From a methodological point of view the design research enquiry undertaken in this paper differs from that of contemporary speculative drawing practices which are primarily grounded in the re-use of vintage pen plotters (such as Carl Lostritto's at the Rhode Island School of Design) and standard industrial robotic arms (such as Pablo García's at the School of the Art Institute of Chicago).³³ By exploring commercially available hardware and its established operational protocols, both Lostritto and García focus their enquiries on the formal and material qualities manifested by the algorithm-based drawings that they produce with those systems.³⁴ In contrast to this, the preoccupation of this paper is procedural: It looks into the computational process itself in an attempt to reveal the different modalities of knowledge unleashed *while producing the drawings*. These differing design research approaches do not only translate into different choices of plotting hardware, but are also reflected in the software components used to manage and translate drawing data. Vintage pen plotters operate using the standardised HP-GL protocol to feed streams of drafting instructions from the computer to the plotting device.³⁵ Modern robotic arms usually receive instructions in equally standardised programming languages such as RAPID or KRL. In contrast, the robotic drawing environment presented in this paper uses a simpler, custom method for direct digital data transferring into its mechanical components. This allows the user to control the robotic drafting process to a large extent, for instance by adjusting the timing of the various data transfer operations occurring within it. As elaborated throughout the next section, this particular aspect is of critical importance to the research argument presented in this paper.

4. A robotic technical ensemble

Looking into the robotic drawing apparatus presented in this paper through Simondon's notion of the 'technical ensemble', this section will describe its individual components –its 'technical objects'-. as well as the modalities of information exchanges they carry out between each other. As pointed out by Sébastien Bourbonnais, the conceptual framework of Simondon's 'technical ensemble' is predicated on the indetermination that arises between its constituent machines, or 'technical objects'. This indetermination is, in turn, manifested in the form of information relays as the 'technical objects' shift, modulate and translate information from one to another.³⁶

The first and second machines in the robotic 'technical ensemble' are 'technical objects' consisting of separate pieces of parametric code, running within a Rhinoceros-Grasshopper software environment. The first machine breaks down the original digital geometry of a CAD file, subsequently reconstructing it as a single, incremental sequence of similarly-sized fragments, which is gradually fed into the second machine. This second technical object translates the now animated sequence into sets of coordinates, which are in turn transferred (as a series of points in space) to a third, hardware-based technical object. Users can control two parameters affecting this two-step transfer process: the number of fragments into which the original geometry is subdivided, and the speed at which these fragments are transferred from one technical object to another. Both conditions generate information relays by affecting how the original data is translated and shifted through the 'technical ensemble'.

The third technical object is a circuit based on an Arduino digital prototyping board that receives the incoming digital stream of coordinate packets through a Universal Serial Bus connection (providing another information relay via its built-in 480mbps transfer rate cap). The custom code in the Arduino board translates the coordinates of digital geometry fragments into two sets of digital signals (motor steps and step direction, one set of signals per drawing axis), which are subsequently converted to analogue Digital Current (DC) signals by means of a stepper motor driver circuit. The two pairs of DC signals modulate the rotations of two electric, 4-phase unipolar stepper motors that constitute the core of the fourth technical object: the flatbed physical machine that translates those rotations into biaxial movements of a drawing head.

We are therefore looking at a technical ensemble, which is composed of four individual technical objects, operating in a range of digital and analogue conditions. In this ensemble a series of relays appear, due to the different rates at which information is transferred across its constituting machinic objects. This is a factor of both the data processing capabilities and limitations of each individual technical object, but also of the losses and additions of information occurring as a consequence of

subsequent conversions across different formats (from lines to fragments, to points, to rotations, and finally to axial coordinates). Critically, in this technical ensemble *the drawing information is produced concurrently with the drawing itself*. The individual technical objects either have no provision of Runtime Data Memory (RAM) or make little use of it, and therefore cannot store the sequential fragments of digital geometry they receive. Consequently, each fragment must be quickly transferred onto the next technical object before being superseded by the next fragment in the sequence. In other words, the timing of the different information relays affecting the system is critical to the operation of the technical ensemble.

As Simondon took great care to emphasise, yet another set of relays emerges in this technical ensemble through the agency of human operators that orchestrate the transferences of information across the different technical objects.³⁷ In other words, we (humans) place ourselves between the machinic components of the ensemble, orchestrating information transfers and adjusting the interaction between components with specific generative goals in mind.

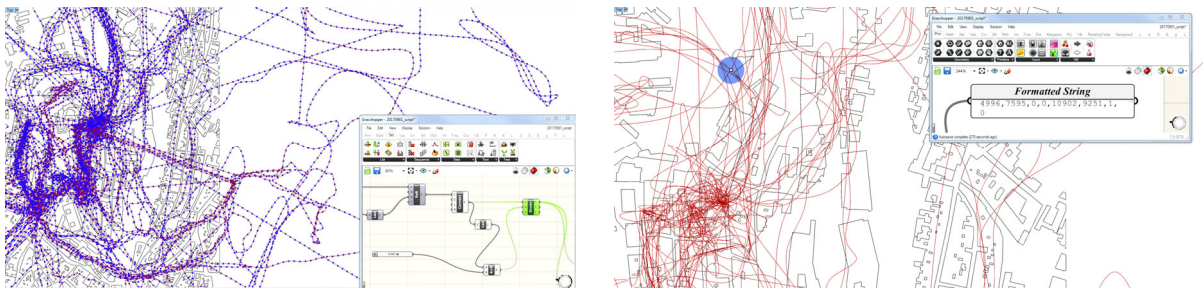


Figure 1: From left to right: Images of the first and second inter-related technical objects comprising the anexact drawing apparatus.

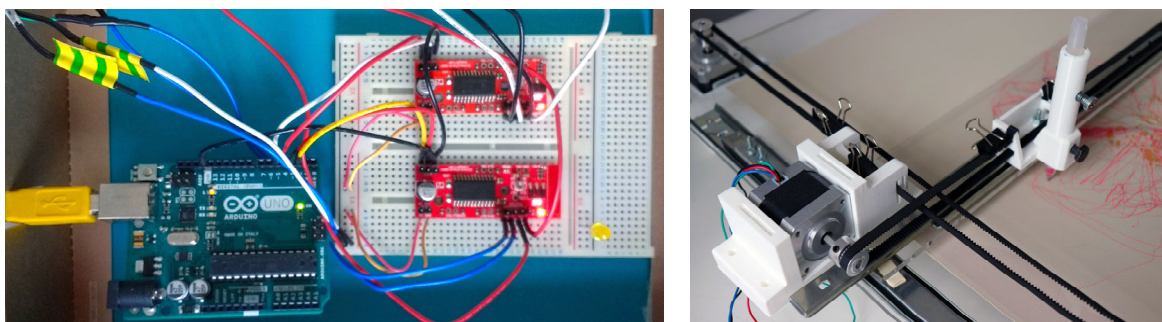


Figure 2: From left to right: Images of the third and fourth inter-related technical objects comprising the anexact drawing apparatus.

5. Revealing the Anexact-but-Rigorous

Once the above setup is put to work – both in technical and conceptual terms – this section will endeavour to answer the question posed at the beginning of the paper: what kind of thought – computational as well as non-computational- is manifested through this productive process? As noted in the previous paragraphs, the source materials originally intended for processing through this technical ensemble are architectural and urban CAD drawings, which can be considered as static assemblages of geometries, installed into Euclidean space.³⁸ The geometries of these source drawings can also be referred to as ‘exact’ in the context of Jacques Derrida’s reading of Edmund Husserl’s seminal essay ‘The Origin of Geometry’.³⁹ Elaborating on the work of Husserl and Derrida, Greg Lynn formulated a distinction between exact, inexact and anexact geometries, which is particularly relevant to the argument presented in this paper. According to Lynn, exact geometries are those that can be reduced to fixed mathematical systems, therefore allowing for their precise reproduction. On the contrary, inexact geometries lack the necessary rigor and precision to allow for their measurement. As a consequence of this, our ability to reproduce them is limited. Finally, anexact geometries refer to constructions that, while being irreducible to specific points and dimensions, are nevertheless rigorous insofar as they can be described with precision. In other words, anexact geometries can indeed be measured and therefore faithfully reproduced. Whereas the exact deals with geometries that are reproducible due to their idealised, abstract nature (for example circles, squares, etc.), Lynn poses the anexact as a type of geometry that can be described and measured with precision, but nevertheless deviates from idealised form.⁴⁰ This is connected to Derrida’s original take on anexactitude, which he defined as a quality that is manifested through vague morphological types, and is therefore predicated on the observation of objects *being perceived as a whole*. Thus, the anexact appears through both the aforementioned morphologically vague types and the methods that are used to describe them. Consequently, a key aspect of the anexact is that its geometrical construction necessarily takes place within the ‘real space’ of what is perceived.

If we look into the robotic drawing apparatus presented in this paper, we may conclude that its machinic agency allows for a slippage of the exact into the anexact. The assembled Euclidean geometries of the original CAD drawings are fed into its technical ensemble, broken down, reconstructed as a single sequence of incremental fragments, and finally relayed as a series of choreographed movements that mark off traces occupying the physical space of the paper. Throughout these relayed processes, references to conventional geometrical shapes (circles and squares but also linear segments, arcs, etc.), and their positioning with regards to a global, metric spatial set are gradually erased from the stream of information. Instead, a regime of local

relationships is established, whereby a single linear sequence emerges by gradually connecting many small fragments of geometry over time. In resonance with the conceptual scaffolding of the anexact, each individual fragment can be referenced only to its preceding element in the sequence, and in turn constitutes the sole spatial and dimensional reference for its succeeding element. Each fragment does indeed cover an individually measurable distance. However, the geometry of the linear sequence as a whole does not emerge from an overarching metric scheme, but rather develops in a self-referential manner.

Thus, besides its immediately apparent capabilities, the technical ensemble that is materialised in the robotic drawing apparatus reveals something else: a modality of anexact-but-rigorous construction, formalised as a dynamic, accumulative occupation of the surface of the paper. In rendering its relayed actions of drawing explicit, it conveys a gradual unfolding of rhythmic gestures over time, which constitutes a fundamental aspect of the anexact-but-rigorous spatial development. The drawing apparatus does not simply translate the original digital drawings into a series of machinic operations – any commercially available desktop printer can do that – but also *amplifies and makes evident* the process of gradually laying out built forms *over time*. Its drawing head amplifies the geometric transactions that underpin the transference of digital geometries onto paper, revealing much more than final forms. All the operations that need to be undertaken for the target geometries to emerge are also physically traced. By re-enacting an original digital territory as a gradual, accumulative occupation, the drawing apparatus becomes an updated version of the *gothic compagnon* or ‘journeyman’ as conceptualised by Deleuze and Guattari. Like the *compagnon*, the robotic apparatus proceeds by rendering visible the full set of discrete instructions that it is meant to carry out.⁴¹ As noted in previous sections, in the particular case of the drawing apparatus, these discrete instructions take the form of custom CNC code.⁴²

To sum up, drawings emerging from the machinic process presented in this paper can be regarded as partial registrations of architectural form, rendered into anexact-but-rigorous geometry through accumulative translations and relays of procedural information. Some further reflections can be added with regards to the hybridisation of analogue and digital modes of production undertaken by the drawing machine. As with any other digital fabrication tool, this device turns a series of discrete instructions of digital code into an analogue, continuous stream of information. By both forcing physical materialisation and rendering the digital-analogue flow of information visible, this technical ensemble installs itself halfway between the abstraction of Euclidean geometry that governs the original digital model and its non-Euclidean, anexact process of territorial emergence, which can only be faithfully re-enacted as an accumulative endeavour.



Figure 3: Drawing apparatus at work.

6. Revealing the Durational component

The robotic technical ensemble posits a take on the anexact that is heavily inflected by the passing of time as a vehicle for accumulative development. On the one hand, it establishes a process whereby continuity is enforced –both geometrically and procedurally- via *concurrent* sequential exchanges of information between its constituent technical objects. On the other hand, and tapping again into Simondon’s lexicon, the informational relays that are built into those exchanges modulate this continuous development via moments of compression and expansion of the informational flow.⁴³

Thus time —or, more precisely, the passing of time— appears here as a viscous pulse, a continuous ‘flow’ of heterogeneous transformations. This leads us to another non-computable element of thought that is enacted by means of the machinic drawing environment. This element is Henri Bergson’s notion of *duration*, which posits reality as a process of continuous transformation that develops over time. In Bergson’s philosophical work, *space* appears in opposition to *duration*. The main characteristic of the former is that it can be ‘counted’, inasmuch as it can be subdivided into homogeneous fragments (for instance, metres or feet) which are discontinuous but also qualitatively

equivalent to one another. By contrast, the latter is a non-divisible succession of changes that are continuous but nonetheless *heterogeneous*.⁴⁴ That is to say, according to the framework of duration the totality of the world exists in a state of permanent change. It is, literally, always *becoming other* – but, critically, there are no ‘cue points’ to tell apart one state of change from another.⁴⁵ Thus, through the mechanism of duration, reality ‘unfolds’ itself as a pulsating medium with a plastic consistency. For Bergson, this plastic pulsation constitutes the ‘real’ passing of time, as opposed to the mistakenly spatialised version of ‘time’ that we can count in minutes and seconds – as if reality could be subdivided into discrete ‘instants’ like image frames in an analogue film.⁴⁶

Two aspects of Bergson’s framework of duration are of particular importance to the drawing methodology presented in this paper. First, Bergson took care to always describe the world as a ‘hybrid’ composite of *space* (quantitative, homogeneous and discontinuous) and *duration* (qualitative, heterogeneous and continuous).⁴⁷ Second, the domain of duration as a temporal succession is not only defined by its all-encompassing character, but also by its historic, accumulative development.⁴⁸

The potential of the robotic technical ensemble as a medium to highlight the durational ‘pulse’ of the real in the urban field in connection with its anexact character, becomes apparent once a variation in the source material is introduced. Whereas initial tests of the machinic environment were conducted by processing static digital files (that is, vector CAD drawings) this variation incorporates a time-based drawing format as input source, consisting of an animated urban plan. As a source of information for machinic processing, this urban plan traces seventy-nine geo-localised paths of individual displacement (corresponding to myself and my students from the University of Cagliari in Sardinia), which were collectively captured via GPS-tracking smartphone apps throughout a single day in April 2017. The animated traces – part of a larger exercise on collective urban data collection - reconstructed the fabric of Cagliari through the lens of the subjective urban geographies of the group. They are rendered as a series of dynamic urban drawings spanning three different scales (metropolitan, urban and local), and formalised as quantized, compressed vector video clips. The materials that illustrate this paper focus on the urban intermediate-scale dynamic drawing, which comprises the central districts of Stampace, Marina, Villanova and Castello. This scale reveals a series of patterns of access emerging from an assemblage of geographical, infrastructural and social conditions. It shows how the paths of students and faculty amalgamate in and around the hub of Piazza Yenne, then extend themselves towards the cluster of buildings that comprise the School of Architecture. The gradual unfolding of these data-based urban traces constitutes a form of ‘urban flow’ articulated through the interaction of heterogeneous sets of components incorporating matter, energy and information.⁴⁹

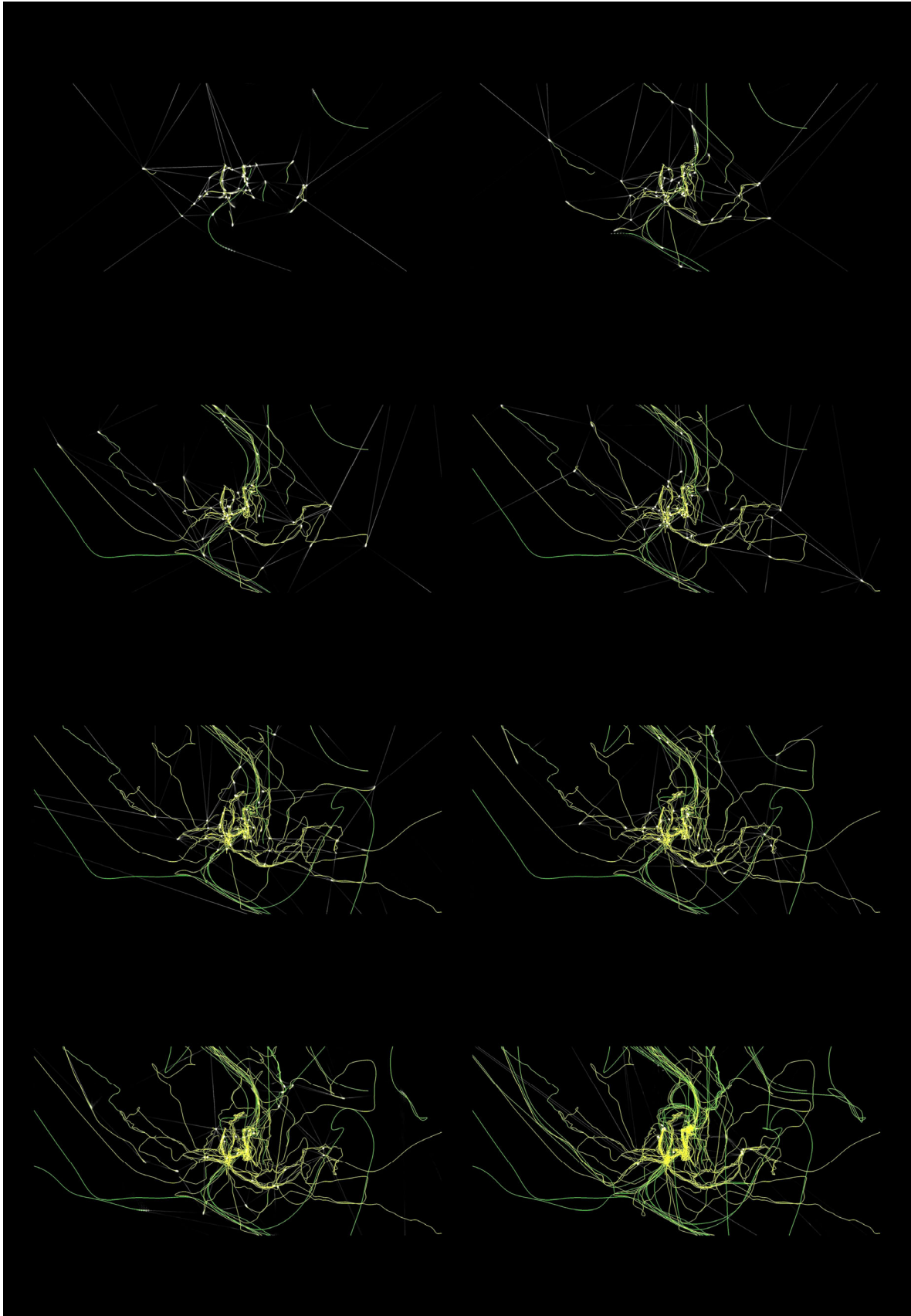
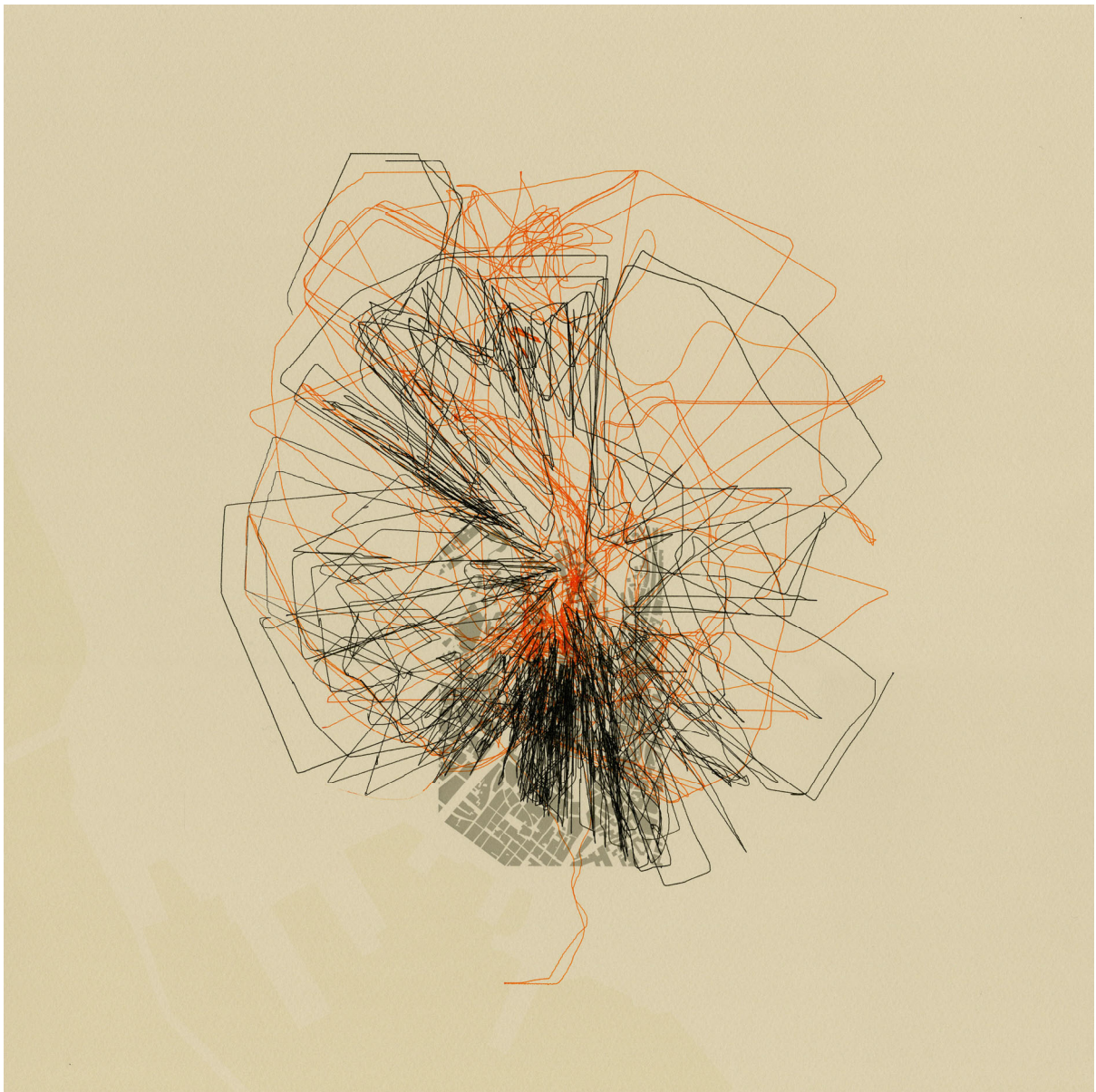


Figure 4: Still frames from the Downtown Cagliari path dynamic vector file, used as input source for the anexact urban drawing.

The effect of running this dynamic digital material through the relayed drawing protocol of the robotic technical ensemble foregrounds duration as a fundamental component of the collectively constructed urban landscape of Cagliari. The territorial occupation originally produced by the student participants in the urban space is gradually remapped onto the surface of the paper, and conveyed as an assembled urban multiplicity. In this process 'urban flow' is articulated as a continuous, yet heterogeneous, occupation of the urban field. This conceptual articulation is emphasised by an operational limitation built into the design of the robotic technical ensemble. Unlike in commercially available pen plotters, the drawing head of the robotic apparatus is never lifted during the drawing process. Therefore, both the original source of digital geometry *and* the additional geometric instructions needed to translate it into a sequence of movements of the plotting head are drawn on the surface of the paper. In doing so, the drawing ensemble renders its own CNC code visible, revealing the geometric 'scaffolding' that supports its displacements through Cartesian space. However, once the animated vector file of movements in Downtown Cagliari is used as a dynamic source of geometry, it soon becomes apparent that this relayed robotic structure is not completely adequate. The drawing head endlessly chases the continuously updating targets of the seventy-nine pathways as they gradually 'play out' at once. As soon as the pen closes in on a point, it is forced to move on to the next position in the temporal-spatial sequence of the animation. The process does not flow seamlessly, as the drawing operation is punctuated by machinic 'stuttering' every time the transfer rates of any two given relays in the technical ensemble become temporarily misaligned. The dynamic urban plan of Cagliari is gradually re-enacted onto the physical surface of the drawing paper as a performative action by the robotic apparatus. As this process develops, we can catch a glimpse of the continuous, yet heterogeneous dynamics of duration affecting the gradual unfolding of collective displacements across the city.

Whereas the time-based robotic technical ensemble is originally 'exact' insofar as it is installed into Cartesian space and Euclidean geometry, it is resituated into the category of the 'anexact' by virtue of the relayed operations of translation that it performs across the digital and analogue domains. Emerging from these accumulated translations, the resulting hybrid digital-analogue drawings convey the simultaneously heterogeneous and continuous character of the collectively assembled urban processes that originated them in the first place.



Figures 5 and 6: Anexact urban plans: Two scanned outputs of the robotic drawing ensemble.

7. Conclusion and further reflections

In a nutshell, the previous sections have discussed our relationship with computational drawing tools, their forms of embedded knowledge and their ability to help us probe and represent elusive urban phenomena. More specifically, two 'non-computational elements of thought' are revealed through the relayed machinic process presented at the core of this paper: Anexactitude is a modality of rigorous, non-Euclidean territorial occupation that is manifested as a dynamic, accumulative endeavour. Duration is an index of the interactions of two overlapping timescales: that of the continuous spatial heterogeneity deployed collectively by urban subjects, and that of the pulsating streams of information transferred through the robotic technical ensemble.

In this process of identifying potential non-computational elements of thought, other related themes emerge. The roles of error, indetermination and the salient presence of the robotic component of the ensemble in the spatial-architectural configuration of the processes it unfolds (all of which echo the sensibilities of Greg Lynn and François Roche in regards to the spatial potentials of robotic technologies)⁵⁰ are also worthy of further reflection. However, at a more general level, it seems particularly important to consider how the relayed, trans-media nature of the work presented in this paper makes it suitable as a form of visual research methodology. Drawing from media archaeologist Jussi Parikka's writings on the epistemological qualities of digital media cultures, we can look into the robotic technical ensemble as a set of topological relationships between digital and physical objects and interfaces.⁵¹ As Parikka noted: "What defines our contemporary culture is that media are calculated and processed in algorithms".⁵² In that respect, and tapping again into Parikka's approach to the historical development of algorithmic media, we can develop a similar narrative of the evolution of architectural-urban drawing media and their embodied forms of knowledge. Throughout the history of architectural and urban representation an increasingly sophisticated interface emerged gradually in the liminal space between the human hand and the paper surface. This interstitial space was originally occupied by a non-mechanical instrument (a pen or a pencil), but machinic components quickly took it over, incorporating their specific forms of embedded geometrical knowledge. In doing so, they inflected the process of drawing with their own mechanical logics but, equally importantly, they also incorporated their own machinic agencies, eventually replacing direct human agency in the action of drafting. As a result, we (humans) acquired a novel form of relayed critical agency, whereby we situate ourselves as both observers and modulators of the machinic process. Through this hybrid mode of production, we can ascertain the anexact and durational modalities of non-computational knowledge as they unfold *in front of us*.

Further to this, other important insights emerge by revisiting the machinic perspective developed earlier in this paper, which draws from Ian Bogost's 'flat' ontological account of the relationship between humans and objects.⁵³ For Bogost, objects manifest unique ways of 'seeing' and 'experiencing' the world as they enter into relationships with other constituent components of their environment – humans and objects alike. This does not mean that objects should be considered 'sentient', but rather that their relational 'points of view' are as valid for articulating knowledge as the 'points of view' of human beings. Still according to Bogost, this unique, non-human 'epistemological perspective' becomes particularly apparent in man-made machines, and even more so in the case of computers. Following this line of thought, the body of work presented in this paper mobilises the machinic 'point of view' of the robotic technical ensemble as a vehicle to gain a broader understanding of urban phenomena related to collective experience, as well as to manifest these phenomena through the actions of drawing.

Hence, by looking at the technical ensemble as a media-based form of embodied knowledge, we pose its robotic environment as a series of enmeshed operational 'units' with the same ontological status as its human operators. Critically, this embodied knowledge emerges *through the epistemological perspective of the machinic ensemble*, very much in tune with Montfort and Bogost's studies of computational platforms.⁵⁴ In building the robotic apparatus and looking into the way it 'sees' and 'experiences' the multiplicitous urbanity of Cagliari as a territorial occupation of the paper surface, we develop a form of philosophical production that puts to work Ian Bogost and Graham Harman's notion of "making things that explain how things make their world".⁵⁵

This quote is also particularly useful to help us understand the value of revealing an exactitude and duration as elements of thought in urban drawing: At present, mainstream approaches to data-driven urban knowledge – such as the paradigm of Smart Cities – foster a somewhat simplistic interpretation of urbanity as a totalising, efficient intermeshing of architectural and infrastructural processes, facilitated by connective layers of computational technologies. In contrast – and against the grain of hegemonic media mechanisms through which the urban is represented as an optimised totality – hybrid media methodologies such as the one presented in this paper can offer powerful counter-narratives of collectively assembled urbanity.

In that sense, and quoting Félix Guattari, "machines do not just revolutionize the world: they can completely recreate it".⁵⁶ Through its unique epistemological perspective, the robotic drawing ensemble *recreates* the urban commons as a subject that emerges – gradually and collectively – through the actions of many individual agencies. In this context, an exactitude is revealed as both the form of this urban multiplicity and a tool to challenge technocratic narratives of numerical

optimization. Likewise, duration is revealed as both the experience of continuous urban heterogeneity – deployed collectively by all participating individuals – and a counterpart to the totalising narrative homogeneity of mainstream, data-driven urban representations.

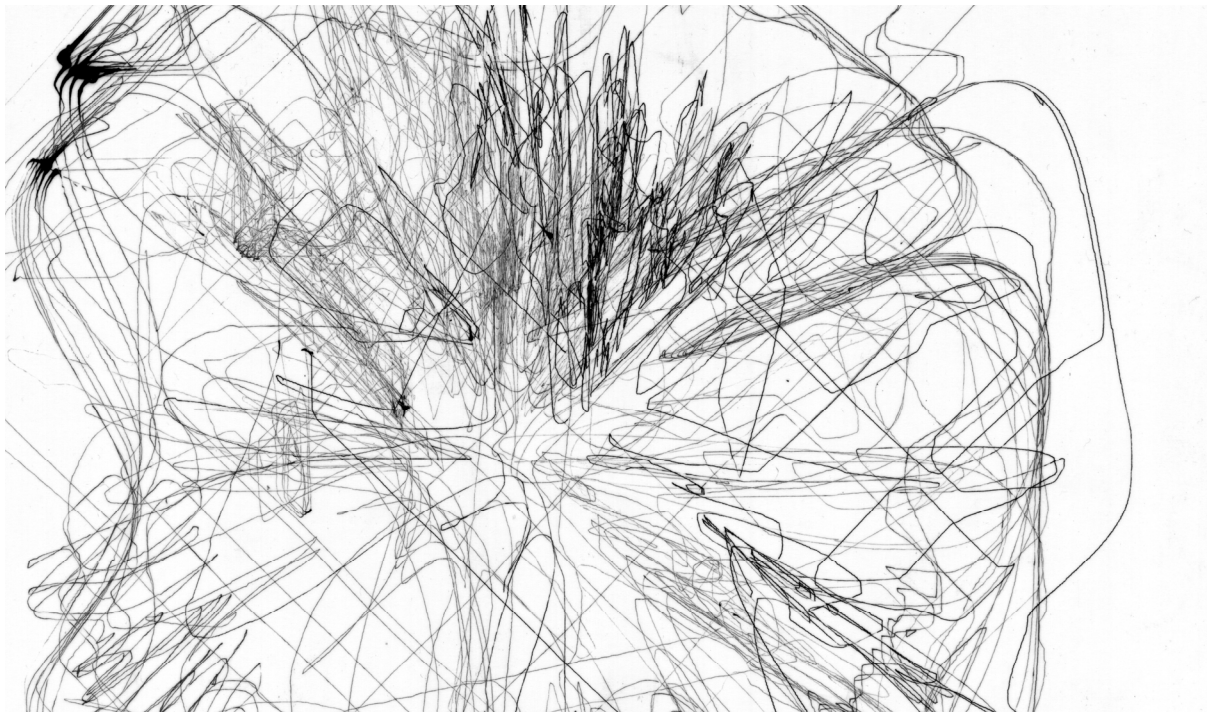


Figure 7: Anexact, durational urban drawing (fragment).

8. Coda: Drawings as by-products of a computational process

Further to this enquiry on the computational and non-computational modalities of knowledge that are facilitated and revealed through the operation of the machinic drawing ensemble, it is worth adding some further reflections on the epistemological status of the finalised drawings that constitute the permanent physical output of their embedded processes. As previously noted when discussing contemporary machinic drawing practices, this paper explicitly poses the locus of knowledge within relayed robotic processes, and thus implicitly relegates drawings to the status of by-products of the machinic operation. Considered at face value, these drawings do have certain aesthetic qualities. However, they are not particularly useful for articulating the notions of Duration or Anexactitude. Instead, either video recordings or direct observations of the machinic process are a more effective medium for conveying those non-computational components of knowledge. In fact, we could argue that the finalised drawings embody the ‘exhaustion’ of the machinic process: the moment in which information no longer ‘flows’ through the system, and its amalgamated dynamic

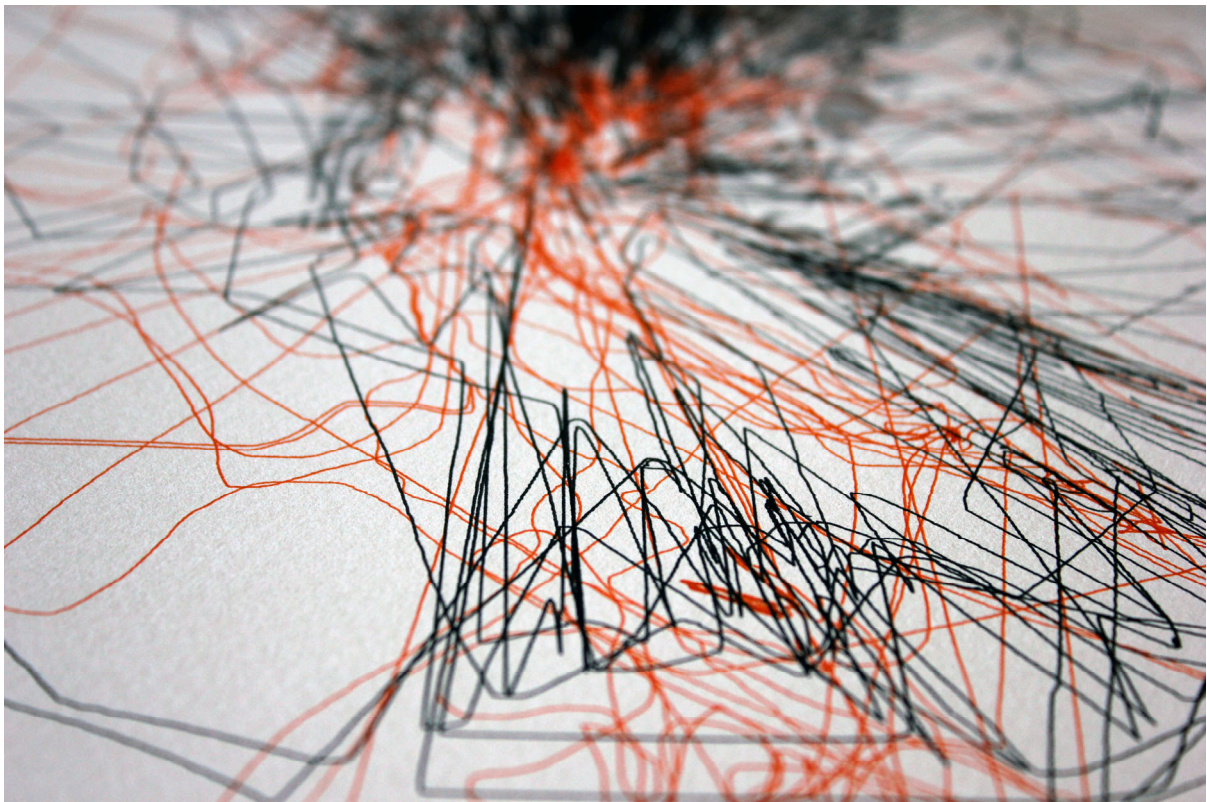
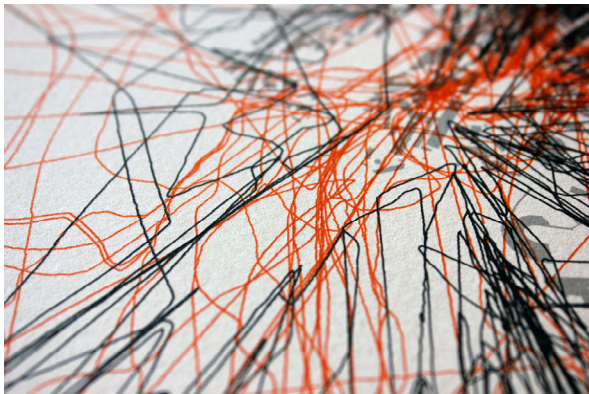
components become 'fixed' onto the surface of the paper. However, and in spite of their somewhat residual role, it is appropriate to wonder whether other subjective, non-dynamic forms of knowledge-as-production may well be embedded into the static drawings. Moreover, we may also wonder if these apparently 'inert' final outcomes of the machinic process can be re-activated as epistemologically active carriers of embedded knowledge.

Both questions can be addressed at different levels. First, much like the preceding lineage of drafting instruments, and in resonance with Simondon's characterisation of technical ensembles, the final drawings can be observed as historical, accumulative manifestations of the relayed relationships between human operators and the mechanics of the robotic apparatus. In this regard, the relayed configuration of the vector-based drawing ensemble presented in this paper yields itself particularly well to incorporating human agency within its robotic plotting operations. Aspects such as the tighter or looser mounting of the pen, the intentional changing of pens throughout the drawing process, or the use of a variety of drawing media (such as pencils, erasers or different types of paper),⁵⁷ incorporate multiple forms of machinic indetermination. These cannot be straightforwardly characterised as information relays, but rather as occurrences emerging from our role as human mediators within the assembled machinic processes.⁵⁸

Second, and in line with contemporary drawing research practices that deal with the re-use of vintage commercial pen plotters,⁵⁹ it is possible to approach the finalised drawings from the point of view of their distinctively analogue qualities. This shifts the focus of enquiry towards the tension between the precision of the digital-algorithmic origins of the drawings, and the serendipitous physicality of the inflections that can be found in the finalised paper outputs. Textural effects such as pen bleeds and ink smudges appear prominently, alongside with unexpected visual 'artifacts' that result from errors and glitches in the information transfer processes across the software and hardware components of the technical ensemble. It can be argued that a different modality of inexactitude, closer to Derrida's original characterisation as 'vague albeit replicable' morphologies can be observed from this particular perspective. Whereas the fundamental morphological aspects of each urban drawing can be replicated, variations in the physical conditions of the medium (the surface of the paper) inflect any attempts at serialised reproductions of vagueness.

Third, it is possible to speculate on how the physical qualities of the finalised drawings can be mobilised as triggers to activate their epistemological potential. Such a speculation taps into the methodological approach of contemporary hand-drawing practices such as Riet Eeckhout's. In an attempt to allow what she describes as non-representational spatial components of the architect's embodied knowledge to surface, Eeckhout photographs her large-scale drawings from close-up,

oblique viewpoints. In doing so, she forces a series of analytical perspectives (both in the spatial and the intellectual sense), which tackle one fragment of the totality of the drawing at a time.⁶⁰ Upon applying Eeckhout's descriptive methodology to the machinic urban drawings presented in this paper, their established epistemological status becomes destabilised: They can no longer be regarded as static recordings of a finalised process (as was the case when scanned frontally and presented as a whole). On the contrary, by looking into their surfaces from close-up, oblique perspectives they reveal a fragmentary, territorial knowledge whereby the graininess of the medium and the topography of linework acquire spatial expressive qualities. This, in turn, refers back to the urban and metropolitan scales of their originating digital data-sets.



Figures 8 and 9: Oblique material-territorial enquiries into the robotic urban drawings.

Bibliography:

- Adams, George, *Geometrical and Graphical Essays Containing a General Description of the Mathematical Instruments Used in Geometry, Civil and Military Surveying, Levelling and Perspective* (London, 1803)
- Aranda, Benjamin., and Chris. Lasch, *Tooling* (New York: Princeton Architectural Press, 2006)
- Bergson, Henri, *Creative Evolution* (London: MacMillan and Co, 1922)
- Bergson, Henri, 'Edinburgh Gifford Lectures. Professor Bergson on the Unity of Our Person', *The Scotsman* (Edinburgh, 6 May 1914)
- Bergson, Henri, *Time and Free Will*, trans. by F.L. Pogson (London: George Allen & Unwin LTD., 1910)
- Bogost, Ian, *Alien Phenomenology, or, What It's like to Be a Thing* (University of Minnesota Press, 2012)
- Bourbonnais, Sebastien, and Julie Rose, 'Information Relay: The Indetermination Between Machines', *Log*, 25 (2012), 63–70
- Cache, Bernard, 'Objectile: The Pursuit of Philosophy by Other Means?', in *Projectiles* (London: AA Publications, 2011), pp. 20–30
- Cache, Bernard, 'Plea for Euclid', in *Projectiles* (London: Architectural Association, 2011), pp. 31–59
- Cache, Bernard, 'Vitruvius Machinator Terminator', in *Projectiles* (London: Architectural Association Publications, 2011), pp. 119–139
- Campbell-Kelly, Martin, and William Aspray, *Computer : A History of the Information Machine* (Boulder: Westview Press, 2004)
- Campo, Mario, *Perspective, Projections and Design* (London: Routledge, 2007)
- DeLanda, Manuel, *Intensive Science and Virtual Philosophy* (New York: Continuum, 2002)
- Deleuze, Gilles, *Bergsonism* (New York: Zone Books, 1991)
- Deleuze, Gilles, and Felix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, trans. by Brian Massumi (Minneapolis: University of Minnesota Press, 1987)
- Derrida, J, *Introduction to the Origin of Geometry* (Stony Brook, NY: Nicolas Hays, 1978)
- Eeckhout, Riet, 'Resisting the Representational', 2013

- Foucault, Michel, *The Order of Things* (New York: Vintage Books, 1994)
- Guattari, Félix, and Sylvère Lotringer, *Soft Subversions : Texts and Interviews 1977-1985* (Semiotext(e), 2009)
- Harman, Graham, *Guerrilla Metaphysics : Phenomenology and the Carpentry of Things* (Open Court, 2005)
- Levine, Stephen, 'Hard Copy and Computer Graphics', in *Computer Graphics. Theory and Applications*, ed. by T.L. Kunii (Springer, 1983), pp. 445–457
- Lostritto, Carl, 'Computational Hatching', *Journal of Architectural Education*, 70 (2016), 83–90 <doi:10.1080/10464883.2016.1122475>
- Lynn, Greg, 'Multiplicitous and In-Organic Bodies', *Architectural Design*, 63 (1993), 30–37
- Mitchell, William J., McCullough, Malcolm, *Digital Design Media* (Van Nostrand Reinhold, 1995)
- Montfort, Nick, and Ian Bogost, *Racing the Beam: The Atari Video Computer System* (Cambridge, MA: MIT Press, 2009)
- O'Hanrahan, Elaine, 'The Contribution of Desmond Paul Henry (1921–2004) to Twentieth-Century Computer Art', *Leonardo*, 0 (2018), 157–162 <doi:10.1162/LEON_a_01326>
- Oosterhuis, Kas, 'Emotive Embodiments', in *Critical and Clinical Cartographies*, ed. by Andrej Radman and Heidi Sohn (Edinburgh: Edinburgh University Press, 2017), pp. 168–183
- Parikka, Jussi, *What Is Media Archaeology?* (Cambridge: Polity Press, 2012)
- Queysanne, Bruno, *Descriptio Urbis Romae, Ou, Comment Faire Le Portrait de Rome* (Paris: Editions de la Villette, 2002)
- Roche, Francois, Matias Del Campo, Sandra Manninger, Ezio Blasetti, Danielle Willems, Roland Snooks, and others, 'Introduction/ Digital Disobediences', in *she would rather do FICTION MAKER* (FRAC Orleans, 2018), pp. 10–12
- Ryan, Daniel, *History of Computer Graphics* (AuthorHouse, 2011)
- Simondon, Gilbert, *Du Mode d'existence Des Objets Techniques* (Paris: Aubier, 1989)
- Stiegler, Bernard., *La Technique et Le Temps 1. La Faute d'Epiméthée* (Galilée, 1994)
- Stiegler, Bernard., 'The Theater of Individuation: Phase-Shift and Resolution in Simondon and Heidegger', *Parrhesia*, 7 (2009), 46–57

Suardi, Giambatista, *Nuovi Istromenti per La Descrizione Di Diverse Curve Antiche e Moderne* (Brescia: G.M. Rizzardi, 1752)

Taylor, Grant D., *When the Machine Made Art : The Troubled History of Computer Art* (Bloomsbury, 2014)

Vic, Marie, and Greg Lynn, 'Interview with Greg Lynn', in *Who are you, François Roche?*, 2016, pp. 63–68

Witt, Andrew, 'A Machine Epistemology in Architecture', *Candide*, 2010, 37–88

Notes:

¹ Cache, B., 'Objectile: The Pursuit of Philosophy by Other Means?', in *Projectiles* (London: AA Publications, 2011), pp. 20–30.

² This paper positions itself within a series of critical voices to the conventionally established means and ends of contemporary computational technologies. Mainstream approaches to architectural computing and architectural robotics seem to pursue a sense of objectivity and validation through ever-increasing rigour and precision. However it can be argued that their take on technology simply reproduces and perpetuates the techno-social top-down processes that they purportedly claim to be superseding, leaving no room for a more profound, systemic consideration of the relationships between design and intuition, humans and computational systems: As Francois Roche puts it "more anthropo-technological than purely dedicated to accuracy, performativity, expertise."

Roche, F. and others, 'Introduction/ Digital Disobediences', in *she would rather do FICTION MAKER* (FRAC Orleans, 2018), pp. 10–12.

³ Parikka, J., *What Is Media Archaeology?* (Cambridge: Polity Press, 2012). pp. 95-97

Parikka specifically refers to the understanding of 'noise' as a 'signal' –albeit not necessarily a signal that carries a particular meaning – in the context of mid-twentieth-century communication theory. In tune with this consideration, noise was no longer considered 'external' to the communication channel, being instead accorded a fully embedded position *within* it.

⁴ Simondon, G., *Du Mode d'existence Des Objets Techniques* (Paris: Aubier, 1989). pp. 145

« Les ensembles techniques se caractérisent par le fait qu'une relation entre les objets techniques s'y institue au niveau de la marge d'indétermination de fonctionnement de chaque objet technique. Cette relation entre les objets techniques, dans la mesure où elle met en corrélation des indéterminations, est de type problématique, et ne peut, pour cette raison, être assumée par les objets eux-mêmes; elle ne peut être l'objet ou le résultat d'un calcul : elle doit être pensée, posée comme problème par un être vivant et pour un être vivant »

⁵ Stiegler, B., *La Technique et Le Temps 1. La Faute d'Epiméthée* (Galilée, 1994), pp. 82–83.

⁶ It should be noted that Simondon did not specifically address the particularities of digital technologies in his account of machinic individuation, especially in regards to its increasing pervasiveness across the technological domain. As Stiegler notes, Simondon seemed to point towards a gradual achievement of technological perfection through "the integration and over-determination of functions".

Stiegler, B., 'The Theater of Individuation: Phase-Shift and Resolution in Simondon and Heidegger', *Parrhesia*, 7 (2009), 46–57.

⁷ Foucault, M., *The Order of Things* (New York: Vintage Books, 1994). pp. 168

“In any given culture and at any given moment, there is always only one episteme that defines the conditions of possibility of all knowledge, whether expressed in a theory or silently invested in a practice.”

⁸ Witt, A., ‘A Machine Epistemology in Architecture’, *Candide*, 2010, 37–88.

⁹ Aranda, B. and Lasch, C., *Tooling* (New York: Princeton Architectural Press, 2006).

¹⁰ Montfort, N. and Bogost, I., *Racing the Beam: The Atari Video Computer System* (Cambridge, MA: MIT Press, 2009), pp. 2–4.

¹¹ Cache, B., ‘Vitruvius Machinator Terminator’, in *Projectiles* (London: Architectural Association Publications, 2011), pp. 119–139.

¹² Carpo, M., *Perspective, Projections and Design* (London: Routledge, 2007). pp. 31-33

¹³ Witt, A., ‘A Machine Epistemology in Architecture’, *Candide*, 2010, 37–88.

It should nonetheless be noted that Brunelleschi’s development of one-point linear perspective, and the associated apparatus he built to produce it, would also constitute a relevant form of encapsulated knowledge.

¹⁴ Carpo, M., *Perspective, Projections and Design* (London: Routledge, 2007). pp. 50

¹⁵ Queysanne, B., *Descriptio Urbis Romae, Ou, Comment Faire Le Portrait de Rome* (Paris: Editions de la Villette, 2002).

¹⁶ Suardi, G., *Nuovi Istromenti per La Descrizione Di Diverse Curve Antiche e Moderne* (Brescia: G.M. Rizzardi, 1752).

¹⁷ Adams, G., *Geometrical and Graphical Essays Containing a General Description of the Mathematical Instruments Used in Geometry, Civil and Military Surveying, Levelling and Perspective* (London, 1803). p.146

¹⁸ Witt, A., ‘A Machine Epistemology in Architecture’, *Candide*, 2010, 37–88.

¹⁹ Mitchell, William J., McCullough, M., *Digital Design Media* (Van Nostrand Reinhold, 1995). p.2

²⁰ Those methods are the precedents of modern photocopying processes, and include techniques such as blueprinting, pellet printing, Van Dyke printing and whiteprint.

²¹ Campbell-Kelly, M. and Aspray, W., *Computer : A History of the Information Machine* (Boulder: Westview Press, 2004). p.16

The work of Herman Hollerith and his Tabulating Machine Company towards the completion of the 1890 census of the United States of America is used here as a general point of reference, although it goes without saying that the evolution of mechanical computers into electromechanical devices cannot be reduced to one single event.

²² Taylor, G.D., *When the Machine Made Art : The Troubled History of Computer Art* (Bloomsbury, 2014). p.16

²³ Mitchell, William J., McCullough, M., *Digital Design Media* (Van Nostrand Reinhold, 1995). pp. 128

²⁴ O’Hanrahan, E., ‘The Contribution of Desmond Paul Henry (1921–2004) to Twentieth-Century Computer Art’, *Leonardo*, 0 (2018), 157–162 <doi:10.1162/LEON_a_01326>.

²⁵ One of the earliest commercially available computer graphics output devices was the Calcomp 565 drum plotter, introduced in 1959.

²⁶ Taylor, G.D., *When the Machine Made Art : The Troubled History of Computer Art* (Bloomsbury, 2014). pp. 115

²⁷ Taylor, G.D., *When the Machine Made Art : The Troubled History of Computer Art* (Bloomsbury, 2014). pp. 125

²⁸ Ryan, D., *History of Computer Graphics* (AuthorHouse, 2011). pp. 43-43

²⁹ Levine, S., ‘Hard Copy and Computer Graphics’, in *Computer Graphics. Theory and Applications*, ed. by T.L. Kunii (Springer, 1983), pp. 445–457.

³⁰ Taylor, G.D., *When the Machine Made Art : The Troubled History of Computer Art* (Bloomsbury, 2014). pp. 255

³¹ Parikka, J., *What Is Media Archaeology?* (Cambridge: Polity Press, 2012). pp. 41-42

³² Mitchell, William J., McCullough, M., *Digital Design Media* (Van Nostrand Reinhold, 1995). pp. 128-130

³³ <http://lostritto.com> and <https://www.pablogarcia.org>

³⁴ Lostritto, C., 'Computational Hatching', *Journal of Architectural Education*, 70 (2016), 83–90
<doi:10.1080/10464883.2016.1122475>.

³⁵ HP-GL (Hewlett & Packard Graphics Language) became the de-facto standard for printer control language. As inkjet systems became prevalent it eventually evolved into HP-GL/2, incorporating support for the definition of pen widths –which was previously determined by the pens loaded into the plotter. Support for contemporary HP-GL implementation, enabling the use of vintage pen plotters with modern hardware and software, is nowadays facilitated by open-source software libraries such as Chipotle:
<http://sites.music.columbia.edu/cmcc/chipotle/>

³⁶ Bourbonnais, S. and Rose, J., 'Information Relay: The Indetermination Between Machines', *Log*, 25 (2012), 63–70.

³⁷ Simondon, G., *Du Mode d'existence Des Objets Techniques* (Paris: Aubier, 1989). pp. 137

« L'opération des machines ne fait pas naître une information, mais est seulement un assemblage et une modification de formes; le fonctionnement d'une machine n'a pas de sens, ne peut donner lieu à de vrais signaux d'information pour une autre machine; il faut un vivant comme médiateur pour interpréter un fonctionnement en termes d'information, et pour le reconvertir en formes pour une autre machine. L'homme comprend les machines; il a une fonction à jouer entre les machines plutôt qu'au-dessus des machines. »

³⁸ Cache, B., 'Plea for Euclid', in *Projectiles* (London: Architectural Association, 2011), pp. 31–59.

Euclidean geometry refers here to a specific geometrical system for the abstract description of space, emerging as a systematic synthesis of formerly isolated theorems developed by earlier Greek and Egyptian mathematicians, and compiled by Euclid in his book *Elements*. It is primarily based on five axiomatic postulates, which originally extended into a series of formal proofs and eventually evolved into a comprehensive, saturated, self-consistent system of 21 axioms, compiled by David Hilbert in *Grundlagen der Geometrie* (1899). Two of its most critical axiomatic postulates are metric measure –the understanding that distances between all components of a given spatial set are defined- and parallelism –the existence of parallel lines within the aforementioned spatial set.

³⁹ Both the exact and the anexact were originally defined by Edmund Husserl in his 1936 paper 'The origin of geometry' and famously scrutinized at length by Jacques Derrida in his introduction to Husserl's text:

Derrida, J., *Introduction to the Origin of Geometry* (Stony Brook, NY: Nicolas Hays, 1978).

⁴⁰ Lynn, G., 'Multiplicitous and In-Organic Bodies', *Architectural Design*, 63 (1993), 30–37.

⁴¹ Rather than producing a set of representational scale drawings, the *journeyman* would proceed by directly delimitating boundary regions as full-scale traces drawn on the ground, thus determining the internal and external outlines of the building on site. In tune with previous distinctions between the exact and the anexact, the work of the master builder is non-Euclidean, albeit not necessarily less rigorous than that emerging from Euclidean geometries assembled through modern scale drawing conventions. Nonetheless, a key difference between these two modes of operation is that, by directly negotiating the nuances of the site as a full-scale, non-neutral surface, the *master builder* has no use for the stasis of idealised geometrical models. On the contrary, he proceeds dynamically by occupying the site with the marking-off of limiting traces, which define themselves gradually and continuously over time. See:

Deleuze, G. and Guattari, F., *A Thousand Plateaus: Capitalism and Schizophrenia*, trans. by Brian Massumi (Minneapolis: University of Minnesota Press, 1987). pp.364-365, pp.367-369 and pp. 390

« The ground-level plane of the Gothic journeyman is opposed to the metric plane of the architect, which is on paper and off site. »

⁴² Oosterhuis, K., 'Emotive Embodiments', in *Critical and Clinical Cartographies*, ed. by Andrej Radman and Heidi Sohn (Edinburgh: Edinburgh University Press, 2017), pp. 168–183.

« Designing with code unravels new horizons both in the world of design and in the world of production. Taking advantage of the architecture of the Computer Numerical Control (CNC) machine – these machines read code, not drawings or 3D models – an immediate relationship between design and machine can be established.»

⁴³ Bourbonnais, S. and Rose, J., 'Information Relay: The Indetermination Between Machines', *Log*, 25 (2012), 63–70.

⁴⁴ Deleuze, G., *Bergsonism* (New York: Zone Books, 1991). pp. 31-32.

This definition reflects Gilles Deleuze's reading of Bergson's 'duration'. In tune with this reading, the drawings presented alongside the textual body of the paper reflect an effort to both capture and manifest this permanent process of *becoming-other* by developing a modality of drawing that enacts a succession of open-ended transformations.

⁴⁵ Bergson, H., 'Edinburgh Gifford Lectures. Professor Bergson on the Unity of Our Person', *The Scotsman* (Edinburgh, 6 May 1914).

« Consciousness (...) perceives multiple physical states, succeeding one another. But it is this multiplicity which is artificial. It is due to the fact that we break up our experience into fragments with a view to greater convenience for action and life. »

⁴⁶ Bergson, H., *Time and Free Will*, trans. by F.L. Pogson (London: George Allen & Unwin LTD., 1910), p. 90.

⁴⁷ Deleuze, G., *Bergsonism* (New York: Zone Books, 1991), p. 47.

⁴⁸ Bergson, H., *Creative Evolution* (London: MacMillan and Co, 1922), p. 18.

⁴⁹ In tune with the original intent of the data collection exercise in Cagliari, 'urban flow' refers here to the diverse dynamic substrates that constitute the subject of data-based urban representations –as exemplified by the Smart City paradigm. However (and in contrast to the top-down character of mainstream approaches to spatialized urban intelligence) the active representations presented as input material in this paper explicitly attempt to open up spaces and tactics of resistance to the homogeneous, technocratic 'smartness' of contemporary urban governance. In doing so, digital techniques are used to address the domain of the commons as a subject that emerges collectively, thus countering institutional narratives of neutral, efficient 'flow' with dynamic narratives of collectively assembled citizenship.

⁵⁰ Vic, M. and Lynn, G., 'Interview with Greg Lynn', in *Who are you, François Roche?*, 2016, pp. 63–68.

⁵¹ Parikka, J., *What Is Media Archaeology?* (Cambridge: Polity Press, 2012). pp. 38

"An increasing amount of interest is then focused not on sensations that the human sensorium registers from media, but on relations between software objects, processes, hardware, networks and more."

⁵² Parikka, J., *What Is Media Archaeology?* (Cambridge: Polity Press, 2012). pp. 38

⁵³ Bogost, I., *Alien Phenomenology, or, What It's like to Be a Thing* (University of Minnesota Press, 2012), pp. 11–12.

Bogost primarily draws the notion of a "flat" ontology from Manuel DeLanda:

DeLanda, M., *Intensive Science and Virtual Philosophy* (New York: Continuum, 2002), pp. 152–153.

⁵⁴ In line with the note above, Montfort and Bogost develop a technical-epistemological approach that looks specifically into the ways in which a machine such as the Atari VCS gaming console "sees" and "experiences" the world.

Montfort, N. and Bogost, I., *Racing the Beam: The Atari Video Computer System* (Cambridge, MA: MIT Press, 2009), pp. 27–29.

⁵⁵ Both Graham Harman and Ian Bogost refer to this practice as "carpentry". See:

Harman, G., *Guerrilla Metaphysics: Phenomenology and the Carpentry of Things* (Open Court, 2005), pp. 2, 72, 176.

Bogost, I., *Alien Phenomenology, Or, What It's like to Be a Thing* (University of Minnesota Press, 2012), pp. 93.

⁵⁶ Guattari, F. and Lotringer, S., *Soft Subversions: Texts and Interviews 1977-1985* (Semiotext(e), 2009), p. 74.

⁵⁷ It should be noted that all these operations, aimed at incorporating a component of 'humanisation' within an otherwise automatic process, were already embedded in commercial vector-based pen plotters since their invention. The drawing ensemble presented in this paper augments the range of these capabilities, precisely by allowing for a higher degree of (human) control to be exerted throughout the process.

Mitchell, William J., McCullough, M., *Digital Design Media* (Van Nostrand Reinhold, 1995). pp. 129

⁵⁸ As Simondon notes, human agency appears as an intellectual operation inserted within the machinic process –interpreting and formatting data streams into intelligible information for subsequent machines- but also at the end of the process itself by 'discovering' the significations that emerge from it.

« L'individu humain apparaît alors comme ayant à convertir en information les formes déposées dans les machines; l'opération des machines ne fait pas naître une information, mais est seulement un assemblage et une modification de formes; le fonctionnement d'une machine n'a pas de sens, ne peut donner lieu à de vrais

signaux d'information pour une autre machine; il faut un vivant comme médiateur pour interpréter un fonctionnement en termes d'information, et pour le reconvertir en formes pour une autre machine. C'est l'homme qui découvre les significations : la signification est le sens que prend un événement par rapport à des formes qui existent déjà; la signification est ce qui fait qu'un événement a valeur d'information. »

Simondon, G., *Du Mode d'existence Des Objets Techniques* (Paris: Aubier, 1989). pp. 137-138

⁵⁹ Specific examples of these practices include Carl Lostritto's *Collection of Circle-Spheres* and Pablo Garcia's *Machine Drawing Drawing Machines*

⁶⁰ Eeckhout, R., 'Resisting the Representational', 2013.