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A Tomographic computation of Spatial Dynamics

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Waning of vigorous discourses about the idea of space as essence in architectural design concurred with the emergence of digital architecture. The notion of space was replaced with the underlying notion of form facilitating optimization of performances and form-generation in digital design ever since. Within the context of digital architecture, the current research investigates a formal method to reintroduce spatial aspects, based on dynamics of architectural space in relation to form, into digital design processes. Accordingly, a computational framework is devised employing the idea of space as dynamic field conditions, in order to capture dynamic interrelation of architectural space with architectural form. That is, spatial dynamics are regarded as data embedded in architectural space, that can imply operational aspects of spatial experiences and / or stimulate corporeal engagements with experiential space, as concepts as action potentials and affordances do (Rasmussen 1964). As a result, the research aims to contribute to the body of knowledge that endeavour to systematize architectural sensibilities that are implicit in design processes by externalization utilizing computation.

Keywords: *spatial dynamics, dynamic field conditions, dynamic displacement*

RESEARCH CONTEXTS

Since the 1890s when Adolf Hildebrand and August Schmarsow crystallized the idea of space as essential for the plastic arts, the notion of space viewed as being most fundamental to architecture persisted to Modernism (Ven 1987). In 1908, Hendrik Berlage postulated that "the aim of our creations is the art of space, the essence of architecture" and half a century later Louis Kahn added: "Architecture is the thoughtful making of spaces. The continual renewal of architecture comes from changing concepts of space".

Despite how fundamental it is to architecture, space is an intangible concept, thus vulnerable to be substituted by more tangible, quantifiable subjects. In 1993, the publication of *Folding in Architecture* edited by Greg Lynn (1993) marked the turn of the millennium, when the avant-garde that evolved out of it was regarded as "the quintessential architectural embodiment of the new digital technologies that were booming at that time" (Carpo 2004). As pointed out by Mario Carpo, the publication was a catalyst for a wave of changes caused by the emerging new field of digital architecture.

One of these changes within architectural discourse was a shift away from the notion of space towards the notion of form, also apparent in Lynn's own writing. Only a few years after the publication of *Folding in Architecture*, the notion of space becomes neutralized and replaced by the notion of vitalized form and its shaping forces in his subsequent publication

Animate Form (Lynn 1999). This transition is characterized by equating the multifarious dimensions of space with the underlying geometric description: "Traditionally, in architecture, the abstract space of design is conceived as an ideal neutral space of Cartesian coordinates" where "geometry provides the apparently universal language with which architecture assumes to speak through history, across culture, and over time". Such elevating of geometry and its resulting notion of form has abetted quests for form-generation practice driven by performance optimisation in digital design (Kolarevic and Malkawi 2005; Oxman and Oxman 2010).

FIELD CONDITIONS IN ARCHITECTURE

Current shift in interest away from space towards form is not a new phenomenon but inherent to the history of the notion of space since its emergence in German aesthetics in the mid-19th century (Mallgrave and Ikonomou 1994). This is due to the fact that space and form are intricately interrelated. As the art theorist and perceptual psychologist Rudolf Arnheim describes it in his study on *The Dynamics of Architectural Form* (Arnheim 1977), "although space, once it is established, is experienced as an always present and self-sufficient given, the experience is generated only through the interrelation of objects. ... Space perception occurs only in the presence of perceivable things".

Human spatial perception, therefore, is inextricably intertwined with the presence of objects; according to Arnheim, the interrelation of form of these objects activates a spatial field that define spatial experience (Arnheim 1977). That is, the spatial dynamics can be seen as relational field condition as explicated by Stan Allen in *From Object to Field*: "Form matters, but not so much the forms of things as the forms between things" (Allen 1997). Such a perspective is analogous to Arnheim's emphasis on interstitial spaces in dynamics of architectural space (Arnheim 1977). Interspaces, as he continues, are filled with gradients whose density and intensity dynamically change according to the configurations of objects, not necessarily strictly bound to metric measurements of and amongst the objects in consideration. Objects interconnected across space activate dynamic forces that influence the density and intensity of spatial field. Consequentially, the dynamic whole displays the characteristics of a highly charged continuous field. Furthermore, multiple number of such field conditions could be incorporated to facilitate new organisations emerging at the moments of intensity within their continuity, since field conditions - even in planar configurations - are capable of revealing hidden values of the system when combined (Allen 1997). (Figure 1)

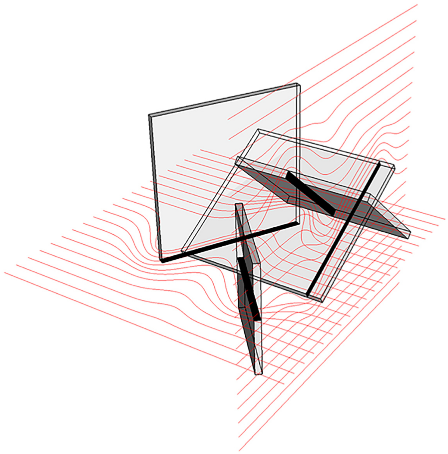


Figure 1
Dynamic field conditions are actuated by relations of objects in the spatial field. Multiple field conditions can be captured and systematically synthesised to reveal otherwise intangible spatial data.

'Field conditions' are quintessential peculiarities of complex dynamic systems. Dynamics in the spatial field become intelligible through emergent variations of density and intensity of the 'field conditions', induced by actuation of spatial field in relation to the objects within the field, rather than as any absolute numeric values; hence, emergent patterns by actuation of the field become 'carriers of information' regarding the dynamics of the spatial fields. Such is an understanding of field conditions familiar to conventional architectural practice where contour maps are used to convey topographic information. Densities of contours, thereby, are residues of geological forces

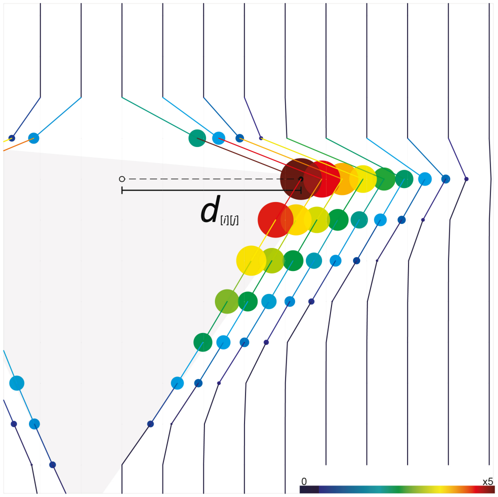
Figure 2
The dynamic displacement function is defined by measuring the deformation of the homogenised state caused by the objects within the spatial field. A color scale is used to visualise the range of values by the dynamic displacement functions.

in action - of the past or the present, or the prognostics of potential movements of objects (animate or inanimate) in the environment.

Referring to non-mainstream digital practices experimenting architectural potentials of digital technologies, digital tools that are currently utilized in architectural design can be tuned and sensitized to detect dynamic forces in the spatial fields activated by objects' relations. The curated digital sensitivity can also be steered to measure the resulting deformation induced by those forces, and to record patterns emerging in dynamic field conditions. Ultimately, the mappings of deformation of the spatial fields not only simulate and analyse complexity of spatial dynamics, but also can externalize spatial data to render them communicable.

TOMOGRAPHIC COMPUTATION OF DYNAMIC FIELD CONDITIONS

Following this conception, dynamics in the spatial field are activated by interrelations of the objects within the spatial field. In other words, the interrelations between objects actuate a neutral field and activates a differentiated field dynamics. Upon activation of the dynamics, the field conditions can manifest two distinct states; the neutral, homogenized state and the actuated, deformed state. Each state can be studied utilizing the tomography-like approach dissecting the spatial fields into multiple layers of spatial data to visualize sectional behaviours of the deformation of the spatial field. The visualization process of the deformations can be illustrated as dynamic displacement function (Figure 2). Within this paper the focus is on spatial phenomena within a single section of the multiple layers of data. The measuring of dynamic displacement functions is based upon single axis of the sectional plane at a time; that is, one operation of the dynamic displacement functions provide readings based upon one axis on the sectional plane. In other words, the definition of the dynamic displacement functions is dependent on the direction value of the axis on the section plane that they are set upon.



Therefore, in order to achieve a comprehensive reading of the deformations on the tomographic sectional plane, multiple measurements need to be acquired by rotation of the axis of the dynamic displacement functions. The computation of the functions encompassing the whole rotational range of the sectional plane can be assembled to constitute an integral mapping of the layer. Such process naturally means that the resulting assemblage of the dynamic displacement functions on the plane is dependent on the rotation resolution of the axis defined in each set of computation of the functions. The higher the rotation resolution of the measuring axis is, the more sensitive the computation towards the geometric particularities of the objects in the spatial field becomes, until increments in the values of its sensitivity stabilize (Figure 3).

The resulting assemblage of dynamic displacement functions depicts behaviours of spatial dynamics on the section plane (the tomographic layer), the dynamics generated by the objects in spatial fields of continuity. The synthesized data of the tomographic layer can also be used to constitute a vector field of the spatial forces that are active on the sectional plane - presented as vector flows in the mapping.

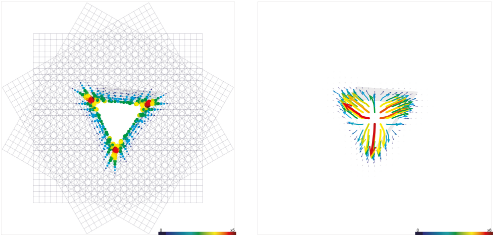


Figure 3
Overlaid multiple dynamic displacement functions produced by rotation of measuring axis on the sectional plane provide a holistic view of the deformation and, thus, of the field dynamics induced by the object in the spatial field (left). This information can be used to generate vector flows that materialise the movement of particles within the object towards the object boundaries (right).

These two sets of information, one regarding the dynamic displacement function and the other the vector flow, allow a reading of the spatial dynamics within the tomographic layer (Figure 3).

TEST STUDIES USING SECTIONAL INFORMATION

To assess the computational framework, a series of test studies are devised using simple structures derived from architectural archetypes introduced by Thiis-Evensen. The cataloguing of archetypes in his study is based on the human corporeality and phenomenological experiences in relation to perceived space form in architecture (Thiis-Evensen 1989; Mallgrave 2018).

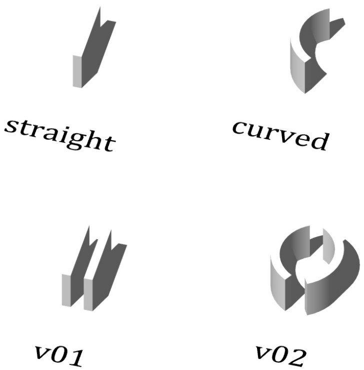


Figure 4
Basic archetypical forms used in the exploration of spatial dynamics by comparative analyses.

Two baseline cases are established consisting of single straight wall for one and single curved wall for the other, followed by variations with the same type of wall added to each baseline case (Figure 4).

Primarily, the vicinity of the object is filled with multidirectional gradients of intensities and densities of spatial dynamics. The gradients progress from lower to higher values in intensity and density of the dynamics, not only towards the objects from farther away in the spatial field but also towards the ends of the walls from the middle (Figure 5). The ends of the walls highly charged with spatial forces can be observed in the mapping of the dynamic displacement functions by actuation of the spatial field, while they appear even more accentuated by the vector flow patterns indicating the attracting forces around (Figure 5). Accordingly, the mappings exhibit that the dynamic displacement function identifies points of special interest as high intensity points.

To discuss the resulting mappings in more detail, in the case of single curved wall (Figure 5b) is presented the condition of asymmetry in spatial dynamics, contrary to the symmetric behaviour of the case of the straight wall (Figure 5a); deformation patterns in the mapping of the dynamic displacement functions by actuated spatial field of the former exhibit differentiation between convex side and concave side of the wall. In addition, the comparison of the vector flow patterns of spatial dynamics in both cases illustrates that the former displays expanded gradients of dynamics with distinctive spatial forces that are active around the middle of the wall. That is to say, curved geometries can generate more diversified spatial dynamics compared to straight lines, since they are more intelligent and better informed, therefore can negotiate differences through continuity (Spuybroek 2004), while expanding the affected field area of basal behaviours engendered by straight geometries.

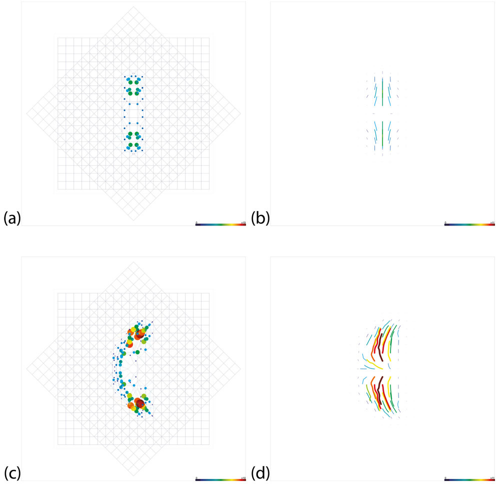


Figure 5
Baseline cases of the test studies consist of the case of single straight wall (Top) and that of single curved wall (Bottom). Each case is presented with two data sets, actuation of the spatial field (Left) and vector flows of spatial forces (Right)

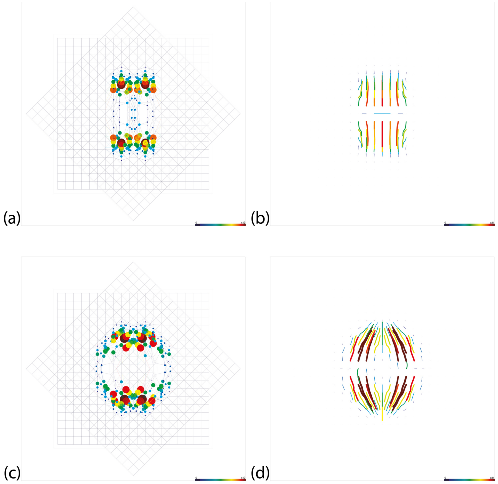


Figure 6
The variations are established based on the baseline cases. Addition of one more element can generate emergent behaviours of more interactions in spatial dynamics.

Each variation established by adding another element in the spatial field affirm latency of more interaction as it appears to amplify the behaviours of each baseline case, a large part of whose features is preserved (Figure 6). The results of the variations enable to speculate capacities of multiple geometries interacting in the spatial fields to generate complex spatial dynamics. Interactions of multiple objects in the spatial fields not only influence the behaviours of spatial dynamics in the interstitial space, but also those in and around each object. For example. The range of intensities of spatial dynamics over the whole spatial field for the single straight wall (Figure 5a and 5b) significantly expands when it interacts with another straight wall (Figure 6a and 6b). In addition, the latter visualizes stronger presence of spatial forces that are perpendicular to the length of the walls, as well as those that are in-between the two, compared to the former. The similar behavioural changes are observed in the case of curved walls. (Figure 6c and 6d) It could be assumed that the computation of spatial dynamics detects symmetries of each object and of the configuration of the objects within the spatial field, which could be explored further in future research.

CONCLUSION

As presented, the research acknowledges that dynamics of architectural experiences - including designing as well as occupying and appreciating - are deeply associated not only with the human corporeality and sense perceptions the human body is capable of processing, but also with intrinsic interrelations of architectural space and architectural form. Therefore, architectural design as space creation cannot be disassociated from the underlying concept of spatial dynamics. As mainstream digital practices in architectural design are increasingly detached from such fundamental discourses despite assertions by precedent architectural theories or studies in the other fields such as neuroscience (Mallgrave 2018), it is imperative to address and incorporate spatial concepts into the current digital design practices.

The computational framework proposed in the paper is the first stage of such attempts. The initial sets of its application demonstrate that gradients in diversified intensities and densities of spatial dynamics operate as carriers of spatial information. Spatial information in architecture can be imbued with architectural intents - 'affordances' or 'action potentials' - that can convey utilization of the space and / or evoke corporeal vitality stimulating the human sense perceptions (Rasmussen 1964; Gibson 1986; Massumi 2004; Mallgrave 2018). That is, continuity of dynamic field conditions is the aspect of space that can convey differentiated magnitudes of spatial information (architectural intents), while complex behaviours of spatial dynamics can be generated through geometric manoeuvres and topological relationship of geometries within spatial fields. Such design operations are usually undertaken by architectural sensibilities throughout design processes that are challenging to be explicitly communicated. Nevertheless, computational design research continuously endeavours to comprehend architectural sensibilities and explicate cognitive processes in design, so as to expand design knowledge while articulating it to be better communicated (Oxman 2006; Terzidis 2004). The current research aims to contribute to such endeavours and explore possibilities of architectural computation beyond the current efficiency-driven use of digital technologies.

With the formation and implementation of initial framework presented in the paper, more variations are to be tested with geometric, spatial and topological variables including curvatures, distances or symmetries. Moreover, further development of the tomographic computation method is to centre around synthesis of the spatial dynamics data, based on sequential relations of tomographic layers. The overarching goal of the research is to develop the tomographic computation to be operative for architectural design purposes, for analysis as well as synthesis of spatial configurations, while systematizing implicit spatial concepts through computation.

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