VITRUVIAN MACHINE: Eight exercises in formal composition

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Abstract. The design machine, an algorithmic structure for design, is considered within current trajectories of architecture discourse to suggest a reinterpretation of the Vitruvian discourse and to produce eight systematic studies in formal composition in architectural design.

Keywords. Formal composition, shape grammars, digital fabrication, design theory.

1. Introduction

Diverse design models and processes are typically proposed to foreground different aspects of description, interpretation and fabrication of architecture components and spaces. New vocabularies, media, techniques and methods are constantly proposed to reinforce, extend or construct from scratch new models. CAAD and manufacturing processes and technologies have been part of this evolving discourse and indeed they have dramatically reshaped design thought and practice. New forms and structures are constantly explored, the gap between design and production closes, complexity and standardization are dealt in new ways.

It is suggested here that the medium that supports a critical examination of all these diverse models of design is computation. Evocative pencil sketches suggest designs that resist interpretation and allow rapid changes of vocabularies of discourse. Computer-controlled design algorithms visualize and fabricate designs that would be difficult or even impossible to be described otherwise. Many other media and methods can be brought to the foreground too. Still, most current models of design pedagogy that are meant to support these computations are neither thought of as computational environments nor provide some generous discourse to account for diverse aspects of design.

The work here takes on an existing algorithmic model for design, the design machine, (Stiny and March, 1981) and correlates that with architecture discourse and particularly -and polemically too- with the earliest surviving treatise on architecture and the three Vitruvian categories of architectural form. More specifically, the work here describes the structure of the architectural implementation of the Vitruvian machine and reports on the findings and implementation of this diagram as an introductory architecture design studio curriculum for graduate architectural education. The explicit formal studies are briefly mentioned and correlated with the output of the students following the procedures. Special attention has been given to the design of the curriculum to promote facility in form-making, and critically investigate permutation and emergence in design. The premise of the curriculum is that these aspects working in tandem are primary modes of invention in design and that the development of both requires rigor of action and of thought, in visual and in the verbal realms, as well as in the linkage of the two.
2. Design machine

The design machine is a schema for design modelled after informational process models of thought. The basic novelty of this model with respect to other informational models is that it requires a third component – that of the language of designs – to augment the basic structure of computation. The design machine consists of four components, a receptor, an effector, a language of designs, and a theory. A brief explanation of the model follows below and a diagrammatic representation is shown in Figure 1.

![Figure 1. A diagrammatic representation of a design machine.](image)

The receptor contains a list of descriptions of events, objects or processes of the outside world. Objects and events have an infinity of properties that may be of interest but the ones that are encoded in the receptor are only those that are matching the given requirements and bias of the machine. This list may contain a finite sequence of symbols encoding texts, drawings, images, sounds, numbers, and so forth. The receptor consists of two parts, a transducer and a linked algorithm to encode the output of the transducer into a description consisting of symbols. The transducer can be a television or infrared camera, a microphone, textual survey responses, two-dimensional or three-dimensional scanner, a satellite recorder, and so forth. Less fancy but infinitely more complicated receptors are own personal sensory machinery – eyes, ears, hands, and so forth. The complexity of the structure of the receptor depends on the complexity of the design of the transducer and the linked algorithm. The output of the receptor can be very straightforward as in a bitmap array of colour values of a scene or very complex as in a textual description of a scene. Furthermore, the relationship of the external event or process and the description of the receptor cannot fixed; different receptors may describe the same process in different ways and different processes may be described in a similar way by one receptor.

The effector contains a list of instructions to produce a response to the receptor. The effector consists of two parts, an algorithm to convert a description of design – set of drawings, datasets, texts and so forth – to instructions to produce the result of the computation and a transducer to instantiate the design. The transducer can be a two-dimensional or three-dimensional printer, a two-dimensional or three-dimensional numerically controlled milling machine, a robot to assemble parts, a speaker, and so forth. Less fancy but infinitely more complicated effectors are our own personal motor machinery – hands, legs, muscles, voice and so forth. The complexity of the structure of the effector depends on the complexity of the design of the transducer and the linked algorithm. The output of the effector can be very straightforward as in a printed bitmap of a scene or very complex as in a painterly description of a scene.

The language component of the design machine is a set of designs. This set contains a finite sequence of symbols encoding texts, drawings, images, sounds, numbers, and so on, and more specifically it includes descriptions of all possible designs of a certain kind. Each language (set of designs) may be defined in terms of some fixed point of interest, say the Palladio designs, and each may be contain diverse descriptions such as three-dimensional models, drawings, or diagrams. Languages may be ordered in any desired degree of complexity defining elaborate structures cutting across spatial and temporal boundaries. Each language may be defined strictly by enumerating the designs in the set or by identifying rules for their generation. The key idea is that languages of design exist independently of other considerations and that their use and value in a design context depends upon the fitness between them and a design inquiry.
Finally the theory component of the design machine is the link connecting the other three components of the machine; it determines the fit between a design and a design context defined by a receptor and effector. Essentially the theory supplies the principles that enable a design machine to choose the most suitable design for a design context.

3. Vitruvian machine.

The design machine suggests a multiplicity of interpretations and applications in various contexts and processes in architecture discourse. Among those the most striking one is the one suggested by its uncanny similarity to the earliest and still quite generous model of architecture discourse proposed by Vitruvius (Morgan, 1914). Vitruvius’ account of the three principles of architecture, encoded in his categories of *venustas*, *firmitas* and *utilitas* - typically translated as beauty, firmness and commodity, directly allude to the Aristotelian foundations of this work and the corresponding interpretative framework of architecture in terms of geometric, material and functional characteristics respectively (Mitchell, 1989).

The mapping between the two models is isomorphic. The receptor can be mapped to *utilitas/commodity* (U) and to function broadly conceived to include technical specifications, performance specifications, engineering specifications and so on. The effector can be mapped to *firmitas/firmness* (F) and to materiality broadly conceived to include all technology specifications and production specifications. The language can be mapped to *venustas/beauty* (V) and to geometry broadly conceived to include all pictorial and spatial descriptions of form. Figure 2 shows the diagrammatic representation of the isomorphism between the design machine and the Vitruvian categories and the resultant diagram for architecture design termed here the Vitruvian machine.

![Figure 2. A diagrammatic representation of the Vitruvian machine.](image)

This diagram for design suggests a complete structure for alternative definitions of design processes. The structure of the design processes and their corresponding formal exercises is derived by a set theoretical analysis of the framework of the pedagogy. The possible combinatorial subsets of the Vitruvian triad are $2^3 = 8$ including the empty set. Including the empty set that suggests a null input and response, the possible theoretical constructs for design action are eight. These constructs are nicely mapped into studies, seminars and readings that inform one another. Furthermore, these eight studies are structured in three phases that correspond to the three subsets of distinct ordinal numbers for the Vitruvian set; excluding the study with null input-output \(\{0\}\), three studies isolate one element of the discourse \(\{V\}\), \(\{U\}\), \(\{F\}\), three studies are comprised by two elements \(\{V,U\}\), \(\{V,F\}\), \(\{U,F\}\), and the last study is the complete triplet \(\{V,U,F\}\). A brief presentation of all eight exercises in formal composition in architectural design follows below.

3.1. NULL

The first study focuses on the pedagogy of the studio and requires a familiarity with the rules of the pedagogy and with the suggested readings. The study does not specify any action for design but instead the emphasis is given in the theoretical preparation to start engaging in formal design actions. Figure 3 illustrates the null Vitruvian machine.
3.2. SHAPE

The second study foregrounds the notion of a geometric vocabulary as a generator for formal design studies. The study is designed to provide a first exposure at the history and logic of geometry in the description and construction of space. More specifically the notion of formal vocabularies is presented through abstract geometrical terms including points, lines, planes, triangles, squares, circles, conic curves, Bezier curves, NURBS, and so forth, as well as evocative spatial descriptions such as porosity, permeability, balance, symmetry, proportion, order, disorder and so on. The goal of this exercise is to isolate spatial descriptions of form and use them systematically in formal composition. Figure 4 provides a diagrammatic representation of the Vitruvian machine foregrounding geometry or shape.

![Figure 4. A partial Vitruvian machine foregrounding geometry.](image)

3.3. FUNCTION

The third study foregrounds the notion of a functional vocabulary as a generator for formal design studies. The study is designed to provide a first exposure at the history and role of function in the description and construction of space. The study explores aspects of algorithmic composition of form based on variations upon underlying functional network structures. These networks are all used as scaffoldings for the generation of form. Figure 5 provides a diagrammatic representation of the Vitruvian machine foregrounding function.

![Figure 5. A partial Vitruvian machine foregrounding function.](image)

3.4. MATERIAL

The fourth study foregrounds the notion of material vocabulary as a generator for formal design studies. The materiality of form - hard, soft, elastic, rough, smooth, opaque, transparent, translucent, and so forth, supports, enables, foregrounds or even contradicts the design description. This study explores aspects of algorithmic composition of form based on the affordability of a variety of different materials to render diverse possibilities in a design.
context. The material properties of form are tested here in recursive and repetitive environments to be used as scaffoldings of formal possibilities. The brief here requires a systematic exploration of different materials and fabrication methods associated with these materials for the design of a module that is able to be employed at various scales to generate or bound space. Figure 6 provides a diagrammatic representation of the Vitruvian machine foregrounding materiality.

3.5. FUNCTION – MATERIAL

The fifth study pairs function and materiality and proposes a loop of formal explorations informed by functional and material considerations. Some functional arrangements are specifically enabled by specific materials and some materials afford different functional organizations to emerge. The loop between the two domains suggests two different trajectories of reasoning, one starting from function and testing against materiality (UF) and the other way around (FU). The brief is designed to explore the interrelation of programmatic organizations and material properties without taking into account geometrical or shape considerations. The object of the study here is the design of an intervention engaging private scale at the architecture building of the studio. Figure 7 provides a diagrammatic representation of the Vitruvian machine foregrounding materiality.

3.6. FUNCTION – SHAPE

The sixth exercise pairs function and geometry and proposes a loop of formal explorations informed by functional and geometrical considerations. Some spatial arrangements are apt to allow specific functions and some functions often emerge in specific spatial organizations. The loop between the two domains suggests two different trajectories of reasoning, one starting from function and testing against geometry (UV) and the other way around (VU). The brief is designed to explore the interrelation of programmatic organizations and formal languages without taking into account material or construction considerations. The object of study here is the design of grammars that merge functional and formal vocabularies for the design of an intervention space engaging public scale at the architecture building of the studio. Figure 8 provides a diagrammatic representation of the Vitruvian machine foregrounding function and geometry.
3.7. SHAPE – MATERIAL

The seventh study explores the relationship between geometry and materiality. Some systems of geometry are informed by specific models of construction and some construction techniques are developed to meet geometric demands. The loop between the two domains here suggests two different trajectories of reasoning, one starting from geometry and testing against materiality (VF) and the other way around (FV). The brief is designed to explore the notion of a prototype structure considered without taking into consideration functional properties. The scale of this study is on 1:1 and since material properties change with scale, the dramatic shift in scale and fabrication requires a rethinking of all materials used in model making during design process; it is quite conceivable that in order to translate the performance and qualities of a design from a small scale to a large one, the material itself and the number and components could change dramatically. The study requires as well critical thinking about structure and construction methods and more specifically about form and formwork. Figure 9 provides a diagrammatic representation of the Vitruvian machine foregrounding geometry and materiality or otherwise between design specifications and fabrication methods.

Figure 9. A partial Vitruvian machine foregrounding geometry and materiality.

3.8. SHAPE – FUNCTION – MATERIAL

The eighth exercise closes the design inquiry suggested by the Vitruvian machine and fully engages all three aspects of the model. The loop between the three domains here suggests 3! = 6 different trajectories of reasoning; VUF, VFU, FVU, FUV, UVF, and UFV. Every theoretical trajectory selected has to be understood, reflected and critiqued upon the ways it informs and it is informed by the other theoretical trajectories of the design process. And still, all trajectories should be present in the end suggesting a totality and complexity that resent unpacking and command alternative interpretative discourses. The brief is designed to allow for a fuller immersion in architecture discourse with complete sets of programmatic requirements, performance specifications, technical specifications, engineering specifications, production specifications and so forth. Figure 10 shows the complete Vitruvian machine.

Figure 10. A complete Vitruvian machine.

4. Discussion

The work presented here showed the first implementation of an existing algorithmic model for design, the design machine, into the heart of architecture discourse, the architecture design studio. The key idea behind the implementation of the computational model upon the studio curriculum is the mapping of the components of the design machine upon the architectural
categories of commodity, firmness, and beauty, the earliest and still quite generous account of architectural principles by Vitruvius. This design model, named here as the Vitruvian machine, is further decomposed in eight parts to guide the design of eight structured studies in formal composition in architectural design. This structured experiment is part of the opening core graduate architecture design studio at Georgia Institute of Technology. All work is documented in the website of the core studio at: http://www.coa.gatech.edu/~economou.

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