



Understanding Architectural Form: A Conceptual Framework

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Abstract

This paper presents a conceptual framework for understanding architectural works. This framework provides an understanding of an architectural building through qualitatively discerning the complexity of issues involved in its design and enabling their systematic integration into a theoretical construct. The premise behind this framework is that in design a better understanding of ‘what’ to design leads to a more informed base to ‘how’ to design, consequently resulting in a more structured and innovative architectural design. Using a grounded theory method, the paper postulates an ontological framework that recasts the Vitruvian triad of *utilitas*, *venustas*, and *firmitas* into spatial form, intellectual form, and structural form respectively, and more importantly expands the triad to include context, and architectural thinking manifested as formative concept, as an integral component in any architectural work, thus closing a gap that existed in many frameworks dealing with architecture. The paper concluded that this framework offers a level of robust understanding of architecture that can become a foundation for a more effective and rational architectural design practice. This foundation can be used as a base in structuring the generation of architectural form as well as the description and analysis of existing works of architecture. Its value exceeds theory framing and extends towards architectural pedagogy as a theoretical framework in teaching design studio.

Keywords: Conceptual Framework, Architectural form, Conceptual form



1. Introduction

As a social phenomenon, architecture is characterized by complexity and linked to multiple bodies of knowledge belonging to diverse disciplines; architectural design typifies a multidisciplinary design domain where architecture, engineering, and construction come together as one, each dealing with a particular feature of the building design and each with its own concepts and interpretations (Roseman & Gero, 1997). Furthermore, architectural design is an integrative and interdisciplinary process with complex requirements of material and immaterial knowledge that calls for a deeper understanding of ‘what’ to design in order to better inform ‘how’ to design (Friedman, 1992; 2003). A better understanding of such complex phenomena requires a multidisciplinary approach that distills concepts across domains and organizes them into a coherent structure, thus creating what is known as conceptual frameworks (Jabareen, 2009). Developing a conceptual framework elucidates basic concepts in a certain domain, develops an essential common language within that domain, and provides uniformity leading to a better understanding of it (Shields & Nandhini, 2013). This paper postulates such a conceptual framework for architecture. It is meant to be an introductory framework for understanding ‘what’ a work of architecture is through developing a meta-level conceptual structure integrating various conceptions of architectural form. This framework facilitates the understanding of architectural form through expounding its underlying constituents, integrating them into a coherent whole, thus allowing for a more structured description, interpretation, and generation of proposed works of architecture, and consequently leading to a more structured discourse of architectural design.

Many researchers and theoreticians, throughout the history of architecture and architectural theory, have attempted to formulate a definition for architecture through the determination of its ruling principles (Gharibpour, 2012); however, most of these attempts can be traced back to one of the oldest and most enduring set of architectural principles proposed by Vitruvius in his treatise *De Architectura* in the first century B.C. Vitruvius’ account of the three principles of architecture, encoded as *venustas*, *firmitas* and *utilitas* - translated respectively as beauty, firmness, and commodity (Stein and Spreckelmeyer, 1999). Associating these three concepts with aesthetics, structure and technology, and function respectively, these three concepts have played an important role throughout the history of architecture where different theoreticians used the same triad with different cultural and historical gradations (Lang, 1987); Wotton (1624), Gropius (1946), Norbert-Schulz (1965), Steele (1973) among others as summarized in table 1.



Vitruvius	Wotton	Gropius (Modern Functionalism)	Norbert-Schulz	Steele
<i>Utilitas</i>	Commodity	Function	Building Task	Task Instrumentality Shelter & Security Social Contacts
<i>Venustas</i>	Delight	Expression	Form	Symbolic identification Pleasure
<i>Firmitas</i>	Firmness	Technics	Technics	Growth

Other researchers emphasized one or more of these aspects and used them as a base for understanding architecture; Semper (2011:1851) emphasized the technical aspect of architecture and attempted to explain the origins of architecture by dividing architecture into four distinctive elements: hearth, roof, enclosure, and mound. Frankl (1973;1914) proposed a critical framework for analyzing architectural styles based on spatial composition, treatment of mass and surface, treatment of optical effects such as light, color, and lastly the relation of design to social functions. Researchers in other fields such Artificial Intelligence and design computing have also proposed schemas that characterize design and design artifacts that are of value for architecture; Stiny and Gips' (1978) presented an 'aesthetic algorithms' machine for the analysis and generation of designs in art and design. Stiny and March (1981) presented 'design machines' as an algorithmic schema to model the design process. Gero (1990) presented function-behavior-structure (**FBS**) framework as a formal representation describing the three variables of a designed object. In characterizing architectural designs, Tzonis (1992) developed the **P.O.M.** system defining performance, operation, and morphology as representation of information contained in precedents, principles, and rules of architecture and feed them into a reasoning mechanism to generate designs. Extending the design machine of Stiny and March, Economou and Riether (2008) presented 'Vitruvian machine' that mapped Vitruvius's triad of venustas, firmitas and utilitas into formal studies of architecture. Dahabreh (Forthcoming) presented the **AD_M** machine as a framework for structuring architectural design knowledge.

However, most of these models did not account for crucial constituents of any architectural work and thus cannot be presented as a conceptual framework for architecture; first, as a building's symbolic performance is inseparable from time and place (Piotrowski, 2001) the relation of the work of architecture to its context and the dynamic role of the context and its affordances in shaping architectural form and influencing design thinking is of extreme importance, accordingly, the context becomes an integral component in understanding 'what' an architectural design is, and has to be incorporated within any conceptual framework. More



importantly, architectural design is a reflexive process that involves critical reflection of the constituents of a design situation; through an internalized design process, the designers adds to a design situation according to certain concepts and reflections (Peponis, 2005), thus framing it in a different manner that goes beyond beauty, firmness, and commodity, eventually affecting the final form of a work of architecture.

Accordingly, design reframing accomplished through conceptual thinking (Dahabreh, forthcoming) not only structure design constituents, but also become embedded within the form of a work of architecture, making it imperative to introduce design concepts as part of ‘what’ an architectural work is and an integral component of any architectural design framework.

Through the qualitative description of a work of architecture, this paper aims to develop an architectural framework that clarifies basic concepts involved in any work of architecture, and integrates them in an orderly manner as well as incorporates context and design concepts as an integral part of that framework. By no means is this framework intended to be a fully detailed account of what architecture is; rather, it lays out the key concepts and constructs and posits relationships among them. These concepts are the building blocks through which designers reason about architectural form schematically and accordingly govern design intelligence. Besides clarifying concepts and relating them, such a framework structures and frames academic debate about architecture in terms of basic taxonomy of concepts, relationship between concepts and propositions and accordingly allows sensible debate to take place. The remainder of this paper is divided into three sections: the second section offers an understanding of what a conceptual framework is. Section three presents the conceptual framework through literature review, and the last section presents conclusions and afterthought.

Setting the stage: definition of a conceptual framework and methodology

Jabareen (2009, p. 51) defined a conceptual framework as “*a network, or ‘a plane,’ of interlinked concepts that together provide a comprehensive understanding of a phenomenon or phenomena.*” The aim of the conceptual framework is to provide an organizing scheme for a phenomenon through the organized structuring of concepts that constitute that phenomenon (Shields & Nandhini, 2013). The constituent concepts that articulate the respective phenomena support one another and establish a framework-specific philosophy. Conceptual frameworks are based on ontological i.e. what they are, epistemological i.e. how they are, and methodological i.e. how formed assumptions (Guba & Lincoln, 1994). Of interest to this paper is the formation of ontological aspect of a conceptual framework. In the field of design computing, ontologies are structured conceptualizations of a domain in terms of entities in that domain and their relationships (Gero & Kannengiesser, 2007). They present a knowledge set



about a subject, and it describes individuals as the basic objects, classes as collections or types of objects, properties and characteristics, and the relations between objects (Aksamija, 2009).

One of the strongest features of conceptual frameworks is that they assimilate knowledge for multi-disciplines and integrates them into a theoretical construct (Jabareen, 2009). As such, for a multidisciplinary domain such as architectural design where art, theory, engineering, and construction among others come together, conceptual frameworks becomes an excellent mechanism for relating different concepts and structuring them as a conceptual construct. As a conceptual frameworks are formed through qualitative analysis, they does not provide knowledge of 'hard facts' but rather 'soft interpretations of intentions' or concepts (Levering, 2002) that aims at neither providing explanations nor predicting outcomes that address questions of 'how' and 'why', but rather providing an understanding of 'what' constitutes a certain phenomenon.

Jabareen (2009) proposed the building of a conceptual framework from existent multidisciplinary literature through conceptual framework analysis. The methodology of conceptual framework analysis is composed of: identifying and mapping selected data source/s. Identifying and naming the main concepts within the identified literature or source of data. Deconstructing and categorizing the concepts in order to identify the concepts the main attributes, characteristics, assumptions, and role; and, consequently, organize and categorize the concepts according to their features. Integrating concepts into constructs or mega concepts, and finally the synthesis of all of these concepts into a conceptual framework. This paper follows the same methodology in constructing the conceptual framework for architecture.

Understanding Architecture: Identifying Concepts

According to Ulrich (1988) the ability to reason about any artifact rests on the ability to abstractly categorize that artifact and provide a minimal description of its structural or salient aspects. For Tzonis (1992) to the core of any intelligent design system should describe significant aspects of how artifacts work, how they are made, what they do in respect to what is expected, how they fit into the surrounding environment, and how all these aspects relate to each other. Nevertheless, describing architectural works is not an easy task; buildings can be described according to the context in which they operate, according to their features and properties as designed artifacts, and/or according to the function they have to perform (Dahabreh, 2006). Hillier, Hanson & Peponis (1984) defined buildings as cultural artifacts that can be regarded as material constructions, spatial arrangements, and objects in a particular style. The fundamental function of the spatial organization, labelled by the German Theorist Paul Frankl (1973) as *spatial form*, is to accommodate human activities that respond to needs and values of different individuals, groups, and institutions. According to Hendrix (2012) the modern connotation of the word function of a building is related to its use or utility as housing human activity/s. By designating a projected building to house a certain institution, the



building is given a label e.g. hospital, which defines it as a functional type. According to Markus (1987) for any building to function effectively i.e.

accommodate the function/s required by an institution occupying the space of the building, the building has to organize people, objects, and activities into meaningful relationships in space. This spatial form represents *what* a building *does*. Thus, it can be inferred that the primary function a building is the organization of space through the building's formal configuration.

As projected buildings do not exist in reality, building programs are the means through which building sponsors or owners describe and/or prescribe their future buildings to designers, and communicate them to users and other stake holders in the projected building (Dahabreh, 2006). According to (Capille & Psarra, 2013) program is both transpatial and spatial manifestation: *“the transpatial aspect defines purposes, activities and roles for different groups of people. In this sense, program can be understood as a social script. The spatial dimensions of program refer to the ways in which this social script is embedded in space through a pattern of distribution, affordances and labelling.”* (Capille & Psarra p 009:18). The spatial division of the space inside a building is not ad-hoc; many buildings have explicit rules about how people, objects and activities are disposed in space so that the spatial embodiment of these dispositions represents the particular practices or knowledge in a certain field, which insures proper functioning of the institution or building (Markus, 1987). These rules impose restrictions on the location i.e. adjacencies and proximity, zoning of different functions, accessibility, and movement between these spaces. Accordingly, spaces housing functions inside the building are arranged in functional zones and spatial relations according to the rules that govern the functioning of the institution. Associated with a building's function are a building's operation and performance. A building's operation refers to how the form of buildings controls, holds or channels, people, objects, equipment associated with activities (Tzonis, 1992). According to Zarzar (2003) a buildings' performance refers to the conditions that a prospective building is intended to bring about in order to carry out the function.

The material construction i.e. structural form shapes space and signifies how to construct the physicality of the building. The material construction of the building involves an engineering and construction aspects (Roseman & Gero, 1997): structural engineering addresses concepts of stability and support of the building, and accordingly is concerned with various structural systems and its material and technology. Mechanical and electrical engineering is concerned with the operation of the building-intersecting in that sense with the functionality of the building-in terms of serviceability and the provision of suitable conditions for the functioning of the architectural building and accordingly is concerned with electromechanical systems. The materialization of the architectural work into a built form is



the expertise of the contractors, which involves the process of transforming raw material into a built form by means of utilizing existing engineering

knowledge and technical know-how. The concern of contractors is constructability and the relationships between the physical elements and the operations and sequence of operations required to construct the building i.e. they are concerned with concepts such as availability, composability, stability, time and place, etc...

At the same time, this material construction has visual qualities such as used materials, color and surface texture, and with aspects of construction and detailing including moldings, grooves, and change in materials etc... that characterize space, thus adding cultural significance and aesthetic appeal, thus becoming a perceptual form. In other words, through their material construction, buildings organize and structure space and transmit social meaning through their physical form. This points confirms with what Hiller (2007, p 24) wrote in *The Space is the Machine* where he stated that:

“A building then becomes socially significant...in two ways: first, by elaborating spaces into socially workable patterns to generate and constrain some socially sanctioned—and therefore normative—pattern of encounter and avoidance; and second, by elaborating physical forms and surfaces into patterns through which culturally and aesthetically sanctioned identities are expressed”

Yet, the material construction has formal attributes such as design elements, architectural vocabulary, design principles, etc...that are not only material in nature but also have a cognitive, conceptual, and affective dimension to them (Peponis, 2005). In that sense, the material construction has an abstract and architectonic aspect, usually expressed geometrically (Unwin, 2003), that signifies *how to logically and formally* structure the materiality of the building. In that sense, architecture can be regarded as an intellectual activity consisting of an underlying conceptual systems (Unwin, 2008) that structure these elements and organize the material construction, generate the formal properties of the building, and accordingly subdivide the space of the building into a spatial pattern. This distinction between the abstract and the material was made 500 years ago by Alberti in the 15th century in his *Ten Books on Architecture*; Alberti distinguished between geometry and material construction of the building where the function of geometry, lineaments in Alberti's terms, is to *“prescribe, and appropriate place, exact numbers, a proper scale, and a graceful order for whole buildings and each of the constituent parts”* (cited in Dahabreh, 2006).

Consequently, the form of the material construction can be read as: a structural form of utilitarian nature that supports the building and structures space, a perceptual form related to the articulation of surfaces and pertaining to sensory perception and experience, and a



conceptual/logical form that orders the elements and regulates the material form. The former three kinds of form related to the material structure correspond to Vitruvius's *structural*, *sculptural*, and *geometric* respectively as identified by Agudin (1995) (fig. 1).

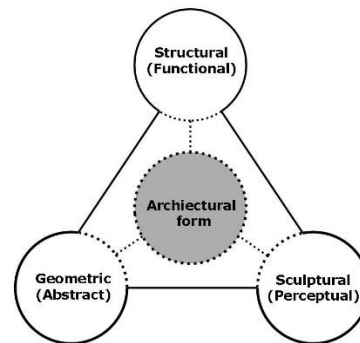


Figure 1 the components of architectural form as proposed by Vitruvius

The spatial form (**SF**) of an architectural building along with its structural (**SF**), perceptual (**PF**), and conceptual forms (**CF**) are interrelated and cannot be separated; each affects and conditions the other and all exist simultaneously in every work of architecture; they all constitute architectural form (fig 2). It should be noted that the categorical distinction between spatial and physical form, is not treated as one intended to capture two or more kinds of organization, but rather as one of recognizing the different aspects of building that become important depending upon the kind of question one asks (Bafna, 2012).

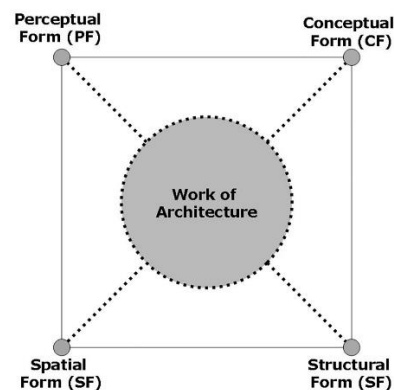


Figure 2 four types of form defining a work of architecture

Hendrix (2012) made a distinction between the functions of form in architecture; a 'communicative' function in terms of expression and representation fulfilled by perceptual and conceptual forms, and an 'instrumental' function in terms of utility and technology as performed by spatial and structural forms respectively. Accordingly, the constituent forms of architecture can be regrouped into three forms: spatial form (**SF**) related to utility, intellectual



form (**IF**) combining conceptual and perceptual form and related to the agency of the ‘intellect’, and a structural form (**SF**) related to technology and construction (fig. 3).

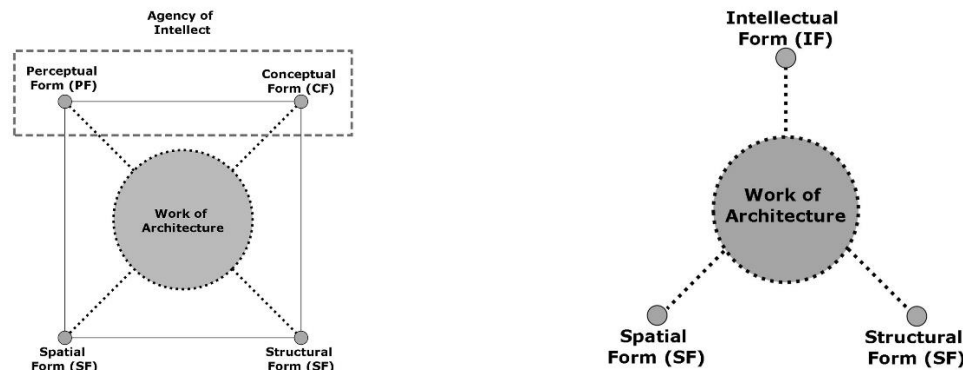


Figure 3: Architectural work understood as spatial, intellectual, and structural forms

The three forms identified above are synthesized through a design process. This design process can be defined as an intentional process that proceeds from a conceptual description of a situation requiring action to a concrete syntactic description of an artifact presented as a response to that situation (Meyer & Fenves, 1992). This process involves a critical reflection upon that situation, thus framing it in a different way that goes beyond its immediate conditions, hence leading to new understanding of it (Dahabreh & Abu Ghanimeh, 2012). This new understanding necessitates the reformulation of design constituents i.e. SF, IF, SF, in an innovative manner to address the conditions of the new situation. Moreover, the synthesized architectural form becomes an object in its own right requiring investigation and examination. This process of reformulation involves the exploration of aesthetic aims through the manipulation of form and the evaluation of the design proposals against a design desiderata (Peponis, 2005). This type of thinking is known in architectural design literature as design concepts. They refer to “*how the various aspects of the requirements of a building can be brought together in a specific thought that directly influences the design and its configuration.*” (McGinty, 1979, p. 215). As such, design concepts are formative ideas (FI) designers use to influence or give form to design (Clark & Pause, 1996). Furthermore, formative ideas include additional aims, or inflections of aims brought about by designers themselves in the course of design as well as the aims of design as intrinsic to the designed object that cannot be initiated before the design process itself (Peponis & Wineman, 2002). According to Schumacher (2011) it is this type of theoretical reformulation and innovation that differentiates architecture from mere building. This theoretical intent manifests itself in the

choices made through the design process and is embedded in it the final form of the building i.e. in the form of the building one can detect the conceptual input. Consequently, an architectural building has an abstract and conceptual aspect i.e. formative idea (**FI**) that integrates spatial, structural, and intellectual form into a unified whole, providing a logical



order that governs and organizes its material construction and expressing how a designer reasoned about the design situation, including what he/she added. Thus, the diagram of architectural form in figure 3 can be recast to integrate formative idea (FI) as the heart of any architectural work (fig 4).

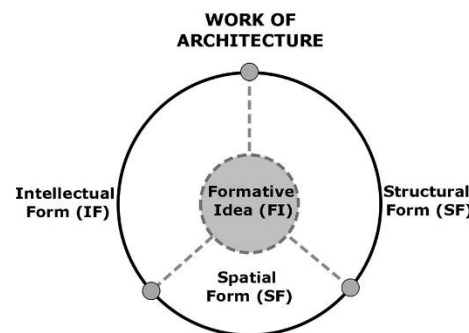


Figure 4 Intellectual form as the integrator of architectural work

Kolodner (1993, p13) defined a case as “a contextualized piece of knowledge representing an experience that teaches a lesson fundamental to achieving the goals of the reasoner.” Conferring with Kolodner that reasoning about any case cannot be separated from its context i.e. the situation under which the case evolved and took place, the final constituent of the conceptual framework is the context (C) under which architectural work was conceived and in which it exists. The inclusion of context as part of understanding a work of architecture stems from the fact that humans exist in a natural physical environment and operate in a socio-cultural one that prescribes their values and goals. Both of these environments establish human needs whether perceived or real, physical or nonphysical. When the surrounding conditions do not meet the needs of humans they “...devise courses of action aimed at changing existing situations into preferred ones.” (Simon, 1998 p 112), accordingly, creating new artifacts that belong to a techno-physical environment (Rosenman, & Gero, 1998). Thus, the satisfaction of human needs belonging to one or more of the environments making up the context becomes the motivation behind the initiation of the architectural design process. These motivations become the goals the designed work has to accomplish. They define the requirements that state what properties, functional or constructional, an artifact should have from the perspective of the goals of the stakeholders (Greefhorst & Poper, 2011). Additionally, the context plays a proscriptive role in architectural design, where through being *constrictive* in terms of its physical or techno-physical nature e.g. topography and climate, or being *controlling* through setting rules and regulations for design e.g. building codes and zoning, context constrains the design by saying what should not or could *not* be done. Finally, the building operation and performance are conditioned by the circumstances of the surrounding context.



As such, understanding ‘what’ a work of architecture is cannot be complete without understanding under what conditions conception, formation, and materialization took place. The final conceptual framework is presented in fig (5).

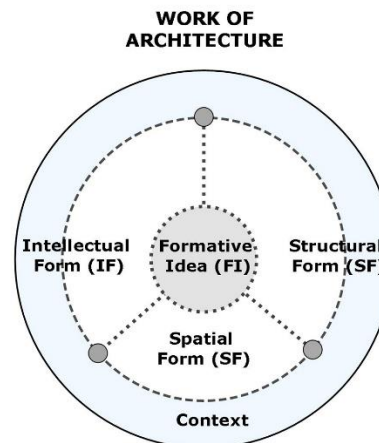


Figure 5 architectural work as an integration of the five concepts

Finally, within the conceptual framework presented in this paper, an architectural building can be understood as a material construction molded through a formative idea (FI), structured by intellectual requirements (IF) that regulates functional requirements (SF), and mathematical and physical necessities (technology and construction) (SF) and all within the constraints of a context (C).

2. Conclusions

This paper proposed a conceptual framework for understanding architectural works. The conceptual framework made up of a spatial form, intellectual form, structural form, formative idea, and context, bridges between the different domains to present a structure of different concepts making up an architectural work and enables the understanding of ‘what’ is a work of architecture. The main thrust of this framework is that it expands the traditional triad of *venustas*, *firmitas*, and *utilitas* of ‘what’ architecture is, which deals with *what* to design, *how* to design it, and *how* to construct it, to include *how* to conceptually think about it, and reintroduces context as an integral concept in understanding ‘what’ a work of architecture is.

The 4F_C framework, through the clarification of concepts, depicts the underlying *status quo* of an architectural work and enables its communication between interested communities. By explicating the *status quo*, a platform is offered for structured debate concerning the nature of architecture and architectural works. Further, shortfalls within existing bodies of knowledge can be depicted, accordingly, opening up venues for further reflection and investigation. Such a framework, is of a pedagogical value where it can be used as *a-priori* framework supporting



architects in the conceptual stages design. Furthermore, it can act as a *posteriori* framework that can be used in architectural analysis and criticism through providing a systematic description and interpretation of built works of architecture. In that sense, it can be used as a didactic tool whether in teaching in the design studios or in the field of architectural morphology.

Finally, the architectural design machine is a generic meta-level framework that only describes generalized concepts of relevant and interrelated knowledge necessary for architectural designing. This framework provides a new foundation for the development of a more intelligent knowledge based design model relevant for architectural design. Furthermore, each of the concepts within the conceptual can be further broken down into smaller and more detailed schemas and frames that can be further investigated and modelled.

3. References

- Agudin, L. M. (1995). The Concept of Type in Architecture: An Inquiry into the Nature of Architectural Form, Ph.D Thesis Zurich: Swiss Federal Institute of Technology.
- Aksamija, A. (2008). Computational Representations of Architectural Design for Tall Buildings. *Complexity* 15(2): 45-53
- Bafna, S. (2012). The Imaginative Function Of Architecture: a clarification of some conceptual issues. In M. Greene, J. Reyes and A. Castro (eds): Proceedings: Eighth International Space Syntax Symposium. Santiago de Chile pp 8117:1-8117:19
- Capille, C & Psarra, s. (2013). Space and planned informality: strong and weak program categorization in public learning environments. In Y. O. Kim, H. T. Park and K. W. Seo (eds.): Proceedings of the Ninth International Space Syntax Symposium Seoul: Sejong University.
- Clark, R. H., Pause, M. (1996). **Precedents in Architecture**. 2nd edition. New York: Van Nostrand Reinhold.
- Dahabreh, S. M. (Forthcoming). The Architectural Design Machine (AD_M): integrating architectural knowledge. *International Journal of Applied Engineering Research (IJAER)*
- Dahabreh, S. M., Abu ghanimeh, A. (2012). Design as Formulation: from application to reflection, *Disegnare idee immagini*, 45, Registrazione Presso, Univerita di Roma pp 76-88.
- Dahabreh. Saleem M. (2006). The Formulation of Design: the Case of the Islip Courthouse by Richard Meier. PhD thesis, Georgia Institute of Technology, GA.
- Economou, A., Riether, G. (2008). The Vitruvian Machine. In Proceedings of the 13th International Conference on Computer: Beyond Computer-Aided Design, Chiang Mai, Thailand pp 522-528.
- Frankl P. 1973. Principles of Architectural History. Cambridge MA: MIT Press, (abstracted and translated by J F O’Gorman from *Die Entwicklungsphasen der Neuren Baukunst* (Munich/Berlin: B. G. Teubner, 1914).
- Friedman, K. (1992). Strategic design taxonomy. Oslo Business School, Oslo, Norway.
- Friedman, K. (2003). Theory construction in design research: criteria: approaches, and methods. *Design Studies* 24: 507–522



- Gero, J. S. (1990). Design prototypes: a knowledge representation schema for design. *AI Magazine* 11(4): 26–36
- Gharibpour, A. (2012). Definition of Architecture: rethinking the Vitruvian Triad. *International Journal of Architecture and Urban Development* 2(4) pp 51-58
- Greefhorst, D., Poper, E. (2011). A Conceptual Framework for Principles: the cornerstones of enterprise architecture. *The Enterprise Engineering Series*. Springer. Volume 4 pp 31-58
- Gropius, W. (1964). Design topics. *Magazine of Art* 40:229-244
- Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* Thousand Oaks, CA: Sage pp 105–117
- Hendrix, J. (2012), theorizing a contradiction between form and function in architecture. *South African Journal of Art History*, 27 (1): 9-28.
- Hillier, B (2007), *Space is the machine: a configurational theory of architecture*. Space Syntax: London, UK.
- Hillier, B., Hanson, J., Peponis, John. (1984). What do we mean by Building Function. In James A. Powell (et. al.) *Designing for Building Utilization*. London, New York: Spon.
- Jabareen, Y. (2009). Building a Conceptual Framework: Philosophy, Definitions, and Procedure. *International Journal of Qualitative Methods*. 8(4): 49-62
- John S. Gero, J., Kannengiesser, U. (2007). A Function-Behavior-Structure Ontology Of Processes. *AI EDAM: Artificial Intelligence for Engineering Design, Analysis, and Manufacturing*. 21(4): pp 379-391
- Kolodner, J. (1993). *Case-Based Reasoning* (Morgan Kaufmann Series in Representation & Reasoning). Morgan Kaufmann
- Lang, J. (1987). *Creating Architectural Theory: The Role of Behavioral Sciences in Environmental Design*. VNR, New York
- Levering, B. (2002). Concept analysis as empirical method. *International Journal of Qualitative Methods*, 1(1), 35–48.
- Markus, T. (1987). Buildings as Classifying Devices. *Environment and Planning B: Planning and Design*, 14: 467-484
- McGinty, T. (1979). Concepts in Architecture. In James C. Snyder and Anthony J. Catanese (Eds). *Introduction to Architecture*. U.S.A: Mc Graw- Hill Book Company pp 208-235
- Meyer, S., Fenves, S. J. and Carnegie Mellon University. Engineering Design Research Center (1992). Adjacency structures as mappings between function and structure in discrete static systems. Department of Civil and Environmental Engineering. Paper 45.
- Norberg Schulz, C. (1965). *Intentions in Architecture*. MIT Press, Cambridge, Mass.
- Peponis J., Wineman J. (2002). The Spatial Structure of Environment and Behavior. In R. Bechtel R, A. Churchman (eds) *Handbook of Environmental Psychology*. New York: John Wiley and Sons pp 271-291
- Peponis, J. (2005). Formulation. *The Journal of Architectural*. 10(2): 119-133
- Piotrowski, A. (2001). On the practices of Representing and Knowing Architecture. In Andrzej Piotrowski, Julia Williams Robinson, eds. *The Discipline of Architecture*. Minneapolis, London: University of Minnesota Press. pp 40-60
- Rosenman, M. A., Gero, J.S. (1998). Purpose and function in design; from the sociocultural to the techno-physical. *Design Studies*. 19(2): 161-187



- Rosenman, M.A., Gero, J.S. (1997). Collaborative Cad Modelling In Multidisciplinary Design Domains. In Maher, M. L., Gero, J. S. and Sudweeks, F. (eds), Preprints Formal Aspects of Collaborative Computer-Aided Design, Key Centre of Design Computing, University of Sydney, Sydney, pp 387-403
- Schumacher, P. (2011). The autopoiesis of architecture (vol. 1) Chichester: John Wiley& Sons Ltd.
- Semper, G. (2011). The Four Elements of Architecture and Other Writings (Res Monographs in Anthropology and Aesthetics). Harry Francis Mallgrave (Translator, Introduction), Wolfgang Herrmann (Translator). Cambridge University Press: Reissue edition
- Shields, P. M. & Rangarajan, N (2013). A Playbook for Research Methods: integrating conceptual frameworks and project management. Stillwater, OK: New Forums Press.
- Simon, H. (1998). The Sciences of the Artificial, 3rd edition. Cambridge, Mass: MIT Press
- Steele, F. (1973). Physical setting and Organizational Development. Reading. Adison Wesley, Cambridge Mass.
- Stein, J. M., Spreckelmeyer, K. F. (1999). Classic Readings in Architecture. WCB/McGraw-Hill, New York.
- Stiny, G. and J. Gips (1978). Algorithmic aesthetics: computers models for criticism and design in the arts. Berkeley: University of California Press.
- Stiny, G., March, L. (1981). Design machines, Environment and Planning B (8): 245-255.
- Tzonis, A. (1992). Huts, ships and bottleracks: Design by analogy for architects and/or machines. In N. Cross, K. Dorst, N. Roozenburg (Ed.), Research in Design Thinking. Delft: Delft University Press pp 139-164
- Ulrich, K.T. (1988). Computation and Pre-Parametric Design'. MIT Artificial Intelligence Laboratory. Technical Report 1043.
- Unwin, S. (2003). Analyzing Architecture. 2nd edition. London and New York: Routledge.
- Unwin, S. (2008). An Architecture Notebook. 3rd edition. London and New York: Routledge.
- Wotton, Sir Henry (1624). The Elements of Architecture; reproduced (c. 1897). Springfield, Mass: F. A. Basstte Company
- Zarzar, K. M. (2003). Use and adaptation of precedents in architectural design: toward an evolutionary design model, PhD thesis, Delft, Delft University Press.