KONRAD WACHSMANN'S RESEARCH METHODOLOGY: DESIGNING A CONTEMPORARY CLIP SYSTEM

Elizabeth Andrzejewski
Pennsylvania State University

As an architect and educator, Konrad Wachsmann's life's work demonstrates an architectural research methodology that uses prototyping and building as a means for testing ideas and theories in both his practice and teaching. In this paper, the author presents a methodological approach used to study the historical significance of Wachsmann's work from the 1940s-1950s and apply the results to contemporary architectural developments. To construct this dialogue with Wachsmann's work the author analyzed the Packaged House System and his theory of universality first in theoretical and historical context and then reconstructed the technical parameters that informed Wachsmann's' design process. Acting as the first part of a dialogue, this analysis of Wachsmann then informed the second part of the dialog where the author's developed a new building system that made use of contemporary tools and fabrication technologies. prefabrication problems addressed by Wachsmann in his work, and then re-examine their potentials through the application of contemporary tools and fabrication technologies. Through building—as an active research methodology of discovery, analysis, articulation, and re-application—lessons learned from Wachsmann's work create new scholarship, and can simultaneously be applied to prefabrication, building technologies, and systematic construction today. The essential dialog connecting historical search/analysis to informed making illustrates a methodology with the potential to further articulate and re-engage historical architectural works and practices through models/prototypes and simulations in ways that result in tactile and intellectual insight into contemporary architectural research projects.

Keywords: Kondrad Wachsmann, research methodology, architectural fabrication.

INTRODUCTION

In this paper, the author articulates an architectural research methodology that can be described as a dialog between a historical analysis of the work of Konrad Wachsmann, and the material development of a contemporary "universal building system." Konrad Wachsmann was a German architect, engineer, and educator who emigrated to the United States in 1941, following the escalation of hostilities during WWII. Trained as a carpenter, architecture for Wachsmann involved both making and theory in his practice from his earliest work with prefabricated wood construction as a lead architect at Christoph & Umack in Niesky (Wachsmann 1995), Germany to his latest built work at USC with the Location Orientation Manipulator in 1971. His ability to ground theoretical concepts, such as universality, through architectural prefabricated systems led to significant contributions in the design of systematic construction, prefabrication, industrial architecture, manufactured housing, architectural machines, and architectural methodologies during the 60+ years of his career. His methodological approach to architecture derived from both theory and practice is evident through his work with universal systems and building assembly such as the Packaged House System, his Mobilar space frame system, Grapevine Structure, and the Location Orientation Manipulator as well as through his academic appointments in Chicago and at USC.

The architectural methodology presented in this paper attempts to illustrate the benefits of creating an essential dialog between a historical analysis of architectural works and practices, and the iterative and explorative nature of architectural modeling/prototyping as a means to conduct architectural research. The methodology discussed could additionally be beneficial to students, practitioners, and designers from many disciplines who wish to actively engage in a physical artifact or theory. The example of this methodology applied within this paper focuses on a research dialog between Konrad Wachsmann and Walter

Gropius's Packaged House System and a contemporary Clip System. The author constructed this cyclical or looping dialog (see illustrations) through the analysis of Wachsmann's theoretical perspectives and built work as recorded in literature, photographs, drawings, models, and buildings (many of which are collected in Wachsmann's seminal writing of 1961, The Turning Point of Building: Structure and Design). This process, of informed making as an analytical tool—rather than as means to test scale and/or material performance as is common in fabrication-based research - led to a unique understanding of Wachsmann's Packaged House System and the serial development of his universal joint, the wedge connector. In this paper, the use of informed making as an analytical tool is employed to understand the design iterations of the wedge connector's evolution, extract, and articulate guiding principles of a Wachsmann-based universal building system, and finally to develop, fabricate, and test a contemporary take on the universal building system. This methodological approach to architecture—an essential dialog between traditional scholarship and traditional forms of architectural modeling/prototyping—forms the basis of a research methodology that engages practices specific to the field of architecture, practices commonly associated with a studio environment and the design of buildings.

PACKAGED HOUSE SYSTEM

Between 1939-1951, Konrad Wachsmann developed the universal joint or wedge connector with Walter Gropius as part of the General Panel Corporation's Packaged House System. The rise and fall of the General Panel Corporation's Packaged House System which ended in 1951 after producing roughly 200 houses are detailed in Herber Gilbert's "The Dream of the Factory-Made House". Though the General Panel Corporation failed, the Packaged House System—prefabricated wood panels jointed together by the specialized universal joint, the wedge connector—was a success for Wachsmann. In a blueprint for the T.D.U.-1/1943 version of the system, Wachsmann describes the system's highlights:

> All the panel units are tightly connected with each other by a 'wedge connector' without using any nails, screws, hooks or glue for the assembly. The erection can be done by unskilled laborers who simply have to hammer in the tightening wedges…the small number of component parts of this system can be applied for an infinite variety of building types and building designs.

Throughout this project, Wachsmann continually evolved the wedge connector as a singular product. Advancing building construction and prefabrication, he developed six joint iterations between 1939 and 1947, addressing the assembly in erecting prefabricated housing. The universal wedge connector and the Packaged House System became the starting point for the author, to analyze and reapply Wachsmann's principles to address contemporary housing.

WACHSMANN'S METHODOLOGY – DIALOG BETWEEN THEORY & BUILDING

In 1949, Wachsmann received his first teaching appointment at the Institute of Design in Chicago as part of the Department of Advanced Building Research. As an educator, Wachsmann involved students in design problems that required intensive physical testing and experimentation, engaging with "industry processes, production, assembly, materials, tools, machine and mass production, modules and standardization, joints and connections" (Ward 1972). Wachsmann also engaged in the theoretical origins/underpinnings of these projects; work that emerged from the "understanding of political, social, scientific and technological processes" (Ward 1972). This methodology of building research routinely employed the use of models and full-scale tests, in addition to writings and lectures that articulated theoretical principles and ideas (Ward 1972). After teaching internationally, Wachsmann returned to California in 1965 where he set up the Building Research Institute at USC which focused on an interdisciplinary approach to architectural research. His work there resulted in the invention of the LOM, (Location Orientation Manipulator), with students John Bollinger and Xavier Mendoza. As a product that combined the most cutting-edge technologies from the automotive and aerospace industries at the time, the LOM, a multi-axis mechanical manipulator specific to architecture, was developed to study the kinematics of building assembly (Bollinger and Mendoza 1971). This Institute and its activity are considered to be formative in the transformation of architectural research from a studio to a laboratory, one with modeling/prototyping/simulation and simulation at its core. The transformation is observed in The Natural Forces Laboratory: Ralph Knowles and the Instrumentalized Studio (Witt and Reznich 2018):

> The articulated and quasi-robotic armatures of Knowle's heliodon and Wachsmann's universal positioner are strikingly similar – both consist of a series of compound radial-arc tracks. Kinematically they are the same device. One is a tool for analyzing, and the other for assembling. Together, they point to the emergence of a mechanical but proto-computational method for design research in the late 1960s…. and with these… experimental machines, the architecture studio was transformed into a laboratory dense with instrumentation.

In the design and development of the LOM specifically, there is a suggestion that this studio-turned-laboratory was more than a space of building (noun) construction, analysis, or simulation; it was a space of experimental building (verb) process innovation through informed making.

In his body of work, Wachsmann actively practiced a research methodology founded on the relationship between architectural theory and the product produced through making and testing. In his book The Turning Point of Building, Wachsmann discusses the importance of fabrication, construction, and prototyping in architectural education:

> Models acquire a special importance when they are built to experiment on, rather than to simply look at… it provides a means of going beyond theoretical investigations and actually testing the standard of performance of any material, product or function…" (1961, 203).

At USC, Wachsmann diagramed the interrelationships between the various components of the Building Research Division, including the Information Center Library, Teacher Training, Research Testing, Faculty, Graduate Studies, and Educational Studies (Wachsmann 1965). A closer examination of the Graduate Studies depicts six different contributing clusters to making up graduate studies. Of particular interest is cluster e which is titled research. This cluster illustrates the relationship between associated methods, products, economics, analyses, coordination, and material (Wachsmann 1965). A closer examination of the Research Testing cluster f labeled development depicts a relationship between analyses, design, coordination, application, economic social, and product distribution (Wachsmann 1965). If we view these terms and diagrams as a culmination of his life's practices and methods, Wachsmann theorizes a design, develops the design considering production methods and materials, explores the economic and social impact of the design, and then analyzes its feasibility—looping backing into the process again.

When designing the Packaged House System, Wachsmann did not simply propose it through drawing, he iterated the system through different versions of the wedge connector across a twenty-year period. When there was to be a factory for producing General Panel Corporation panels, he did not relegate himself to theorizing about how the panels might be fabricated only, he designed the factory layout and its resource tendons himself. In his work with the Packaged House system, he actively participated in a total building process where everything was designed and considered—from material handling, fabrication methods, economic and social demands, to final product distribution and assembly of the architectural prefabricated system. Wachsmann announced his vision for the future of the architectural field in 1961 at the Aspen Conference, and later clarifies this vision in his unpublished autobiography entitled 1901-2001 Timebridge (1980, 380):

> When I said 'to build is everything', I meant to build includes and embraces everything… the common effort, the common evaluation, the collective work, the use of everything this time has to offer, this is building.

Translated into architectural research, his process and practice of physically manifesting theories through making or fabrication is evident in his search for the universal, articulated and developed through many physical and theoretical forms in his life's work.

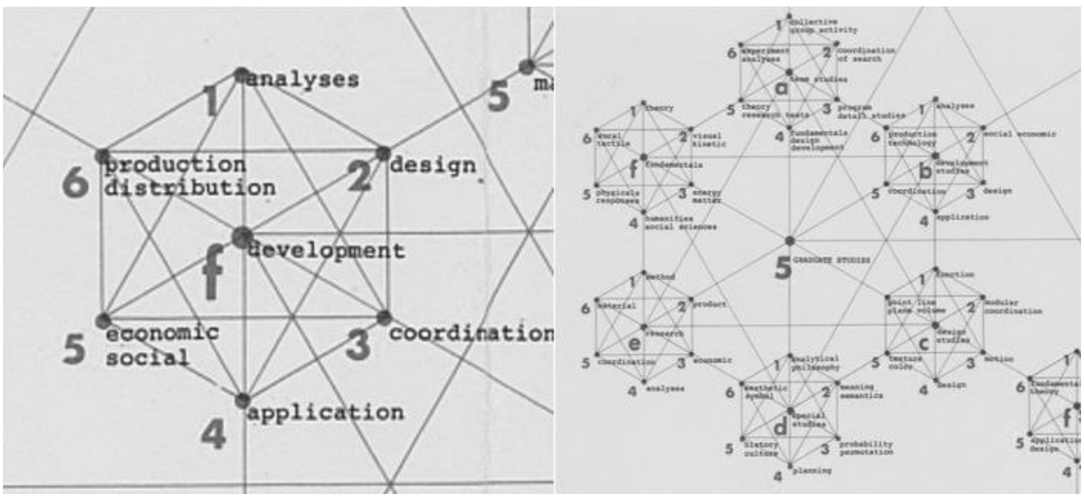


Figure 1: Wachsmann's development of the Packaged House System and wedge connector were influenced by the changing landscape of housing needs, and a continual evaluation of the design by theory and timely outside factors. Source: Konrad Wachsmann from ADK Archive, Berlin 1965

With the wedge connector, Wachsmann begins with problems inherent in the process of prefabricating housing. During and after WWII, the US government was in need of housing that could be erected efficiently, assembled by anyone, then dissembled, moved, and reused somewhere else. Each version of Wachsmann's wedge connector and subsequently the Packaged House System participated in a feedback loop of evaluation based on how it functioned and measured up to achieving true universality. Wachsmann defines a systems-based problem around the characteristics of universality, develops the system, and then evaluates the performance of the system for success at solving the defined problem, and then improves or changes the design based on more accurately defined goals for the system. This feedback loop as shown in figure 2, creates an essential dialog - as architectural research - between a physical output and its theoretical significance.

METHODOLOGY – DIALOG BETWEEN WACHSMANN & CLIP SYSTEM

From 2016-2018, a dialogue with the universal joint led to a rearticulated synthesis of universal principles for creating building systems. In Wachsmann's work, a universal building system is 1) efficient, 2) unskilled, 3) mobile, 4) scale-less, and 5) flexible/adaptable. These five principles articulated a basis for generating a contemporary universal building system. Overtime, the research uncovered a deeper understanding of Wachsmann's joint's open center, the

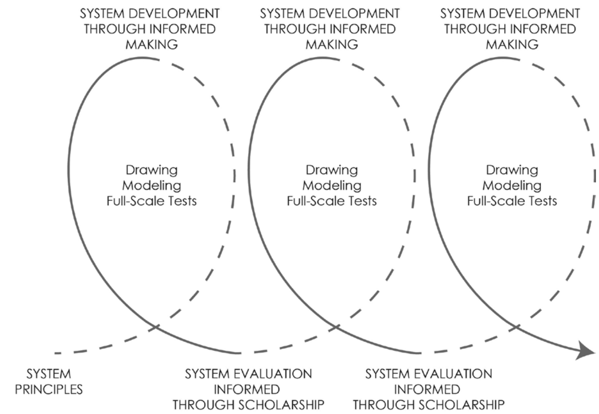
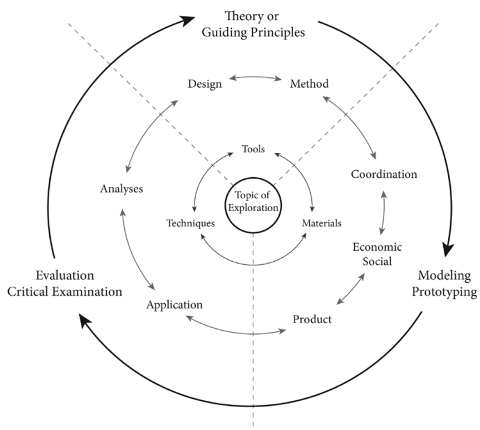


Figure 2: As Wachsmann develops his universal building systems, a dialog is created between the initial principles and the development of the system through drawings, models, and full-scale tests. With each iteration the System evolves. Source: Author 2020.

module, and systematic assembly. Though these system qualities are described in The Turning Point of Building: Structure and Design, actually working through the problem by constructing full scale tests and mock-ups revealed the real-life importance of Wachsmann's Universal. In an active extension of scholarship, the author uncovered Wachsmann's process through building. The resulting Clip System differed from Wachsmann's, placing more emphasis on panels created from available materials rather than relying on factory produced panels. The Clip System is made up of clips and nodes; clips attach to any available panel; nodes lock the panels together. Throughout co-development of clip, tool, and panel (guided by Wachsmann), 3D printing, plasma cutting, and forging were used to develop working prototypes of the system. Full-scale testing produced an 80"x85" unit, assembled by two people in 80 +/- minutes. While we are unable to have a conversation with Wachsmann about his motivations for the universal joint, this dialogue-through-building and testing allowed the author to learn from/re-engage his work by replicating his problems, parameters, and introducing new technologies and building methods to solve them.

Wachsmann's methods as visualized above in figure 4 could be applied to many areas of study. An example of a feedback loop that could be applied to various studies is pictured in figure 4, where the research topic of exploration is informed by theory or guiding principles, modeling, and prototyping, and evaluated through critical examination of the artifacts produced.

This same architectural methodology was applied to a research project, figure 4, which asked, "How can revisiting Wachsmann's 'universal joint' and the failed prefabrication systems of the past, inform the development of a new joint and panel-based open building system—one that accommodates low-skilled labor and allows for fast assembly, and flexible reuse of material and modification?" The research team applied this methodology which focused on understanding, informing, and furthering Wachsmann's work through the fabrication and analysis of reproductions tied to the historical development of his joints/connectors. While many students of architecture are simultaneously schooled in office practices and some degree of material knowledge, testing and analysis, this work focusing on Wachsmann's universal joint was led by an architecture graduate student with professional office experience and considerable experience in fabrication; skills/technologies including blacksmithing, welding, machining, and additive manufacturing. The working methodology shown in figure 6 eventually resulted in a contemporary Wachsmann-informed universal building system, one



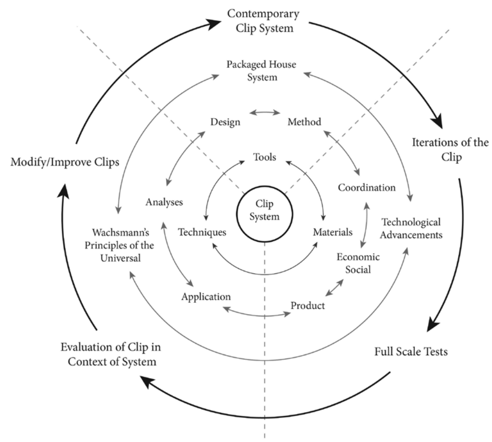


Figure 3 (left): Proposed methodology informed by theory or guiding principles, modeling, and prototyping, and evaluated through critical examination of the artifacts produced. Source: Author 2021.
Figure 4 (right): A contemporary universal system developed from a cyclical dialog considering Wachsmann's work with the Packaged House System and his theoretical universal principles. Through this process, Wachsmann's work influenced this Clip System and its development informed the research team's understanding of the Packaged House System and Wachsmann's theories of universal. Source: Author 2021.

generated from the co-development of clip connectors, panels, and associated tooling, designed through empirical testing, full-scale fabrication, and a close reading of Wachsmann's technological priorities as related to the "universal". The team's active engagement with a full range of fabrication technologies facilitated a deeper discovery of the difficulties and limitations of working with certain materials, construction systems-related issues/limitations, and a correlated focus on re-articulating principles of "universal" in the context of contemporary industrial housing.

APPLICATION OF METHODOLOGY – A CONTEMPORARY CLIP SYSTEM

The wedge connector, Wachsmann's universal joint, lies physically and metaphorically at the center of the Packaged House System. The team instinctually began by seeking to understand the Packaged House System through a deep analysis of the wedge connector as shown in figure 5. Initial studies focused on drawings and laser-cut cardboard models based on images of the 1947 version of the wedge connector as published in Wachsmann's book The Turning Point of Building (it was the final version and most idealized). Though this first study was slightly inaccurate, it demonstrated two things: first, the connector itself has a very specific assembly order which highlights the importance of assembly order in the system as a whole. Second, though the wedge connector is rarely depicted situated within the panels, they are an equally important component of the joint, allowing it to "wedge" together.

Next, the scale of the joint was studied further through a close reading of connector patent drawings of the connector dated 1945 as shown in figure 6. Though these documents did not yield the exact size of the wedge connector, its approximate size was determined based on the size of the panels which were denoted in these patents. Though there are discrepancies within the patents themselves, the small size of the connector was later verified at the Akademie der Künste archive and the viewing of an authentic Wachsmann wedge connector. Modeling and drawing each version of the wedge connector was what ultimately led to an understanding of its function and scale. In fact, it fits comfortably in the palm of a human hand.

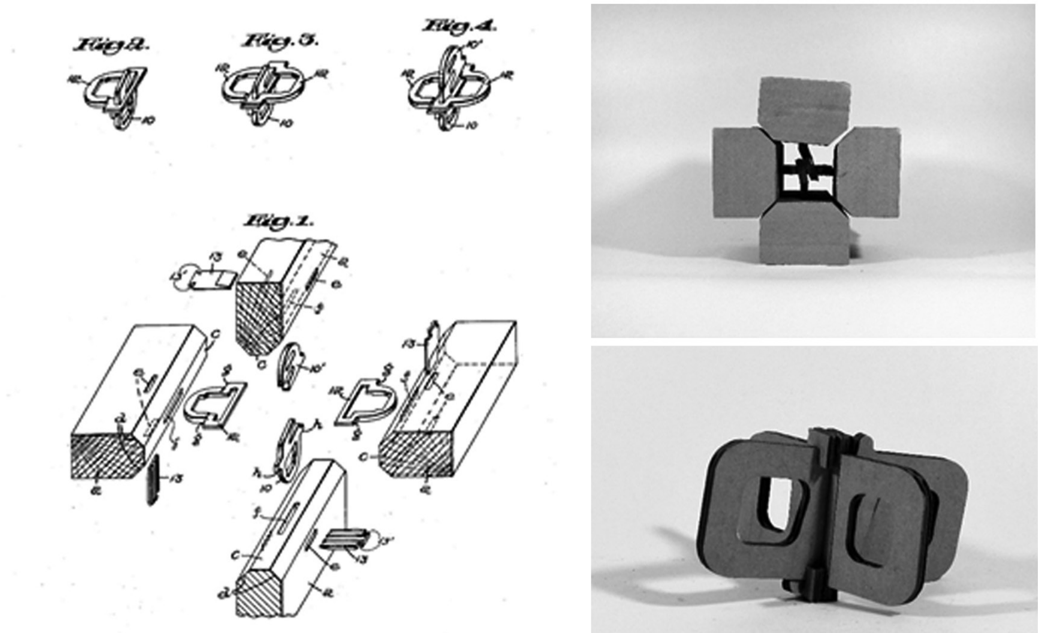


Figure 5: Studying patent drawings of the wedge connector as well as drawings and images from The Turning Point of Building, led to cardboard replications of the universal joint. These 3D models allowed the team to study the assembly order and understand a sense of scale. Source: US2421305, 1947 (left), Author 2021 (right).

With each study of the wedge connector, the team traced design changes to reasoning and logic that led to the physical evolution of its design, as recorded in historical documentation. During this process of discovery, there was a simultaneous dialog between the informed production of digital models, drawings, and 3D prints linked to a historical analysis of drawings and social/political factors that influenced and changed the objectives of the Packaged House System. The critical realization made using the dialog method was that relying solely on either reproductive models or historical analysis alone would have resulted in an incomplete understanding of Wachsmann's connector. The diagram pictured below, figure 7, illustrates the six distinct evolutions of Wachsmann's wedge connector, which can be understood as three phases of development from approximately 1939 to 1947 (Andrzejewski 2018, 21-30). Detailed findings of its evolution are recorded in a chapter that the team contributed to The Art of Joining: Designing the Universal Connector, which was published at the conclusion of the 2018 Bauhaus Lab. This was specifically informed by various patents, images, and blueprints of the Packaged House System. The dialog between the theoretical evolution of the wedge connector and its three-dimensional composition, figure 8, led to a deeper understanding of the system as a whole, and aided in articulating Wachsmann's underlying principles of a "Universal Building System".

A close study of Wachsmann's process of iterations through sequential versions of the wedge connectors reveals that the change in the design was not influenced solely by the functional requirements of the panel and associated system; they were products of the shifting world climate during and after WWII and developed in relation to fabrication methods available at the time. Figure 9, overlays our looping dialog cycle into Wachsmann's evolution of the wedge connector, and introduces some of the influencing factors which transformed the design development along the way. Sabatto details these historic economic

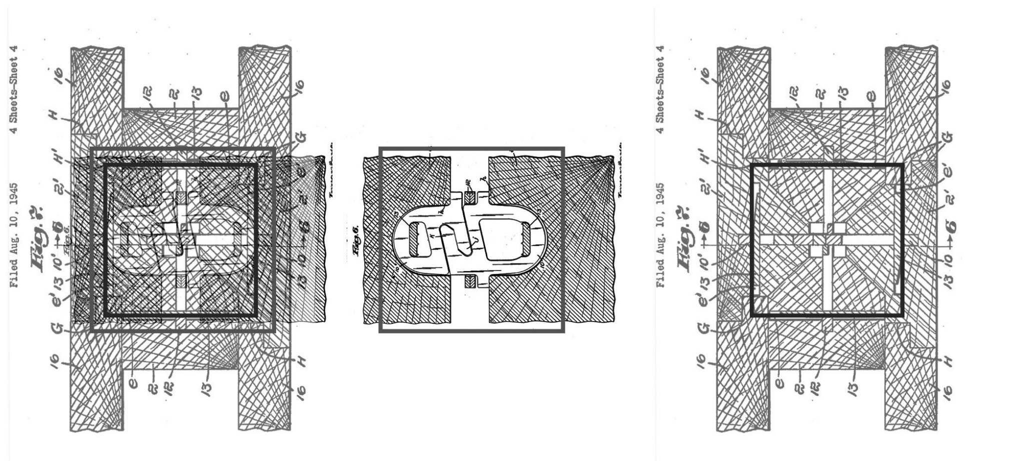


Figure 6: Study of wedge connector size from patent drawing reveals discrepancies in size between drawings. Source: Adapted from Patent US2421305, 1947.

and technological influences in "From Keying to Wedging: the Optimized Workability of Constructional Systems Designed by Konrad Wachsmann During the Cold War Under the Supervision of the North American Governmental Agencies" (Sabatto 2012).

After gaining a basic understanding of the wedge connector's development and scale, principles of Wachsmann's idealized universal building system began to emerge. Wachsmann' s obsession with themes of universality is evident in his approach to systems which did not stem from a need or desire to create a specific building, but rather create building systems composed of a series of universal parts without a predetermined outcome (endless/infinitely expansive architectures). After articulating the theoretical principles Wachsmann's universal by re-examining/replicating elements of his work, the author began to test them in the development of a contemporary universal building system. The goal was to produce a Wachsmann-informed architecture that could be used to construct an almost unlimited number of architectural possibilities, by anyone (that is unskilled workers), in a variety of environments. The author's close study of major works, publications, and patented systems—in dialog with routine informed making as depicted above in figure 6—revealed that, for Wachsmann, universal systems: 1) strive to be efficient in their assembly/disassembly process, 2) are accessible to the unskilled laborer, 3) are mobile, 4) are scale-less, and 5) are flexible/adaptable providing for material reuse. These five principles, efficient, unskilled, mobile, scale-less, and flexible/adaptable—not explicitly articulated in existing Wachsmann literature but derived from this research—became guiding design principles for the development, fabrication, and testing of a contemporary take on the universal building system.

The first step in designing the system was to reform Wachsmann's principles of the universal to accommodate material reuse and panels to be made from the system itself, rather than necessitating they be prefabricated in a factory. This substitution, of multi-use quality for scale-less, would allow the resulting system to engage today's DIY builder culture and allow for the possibility of panels made of repurposed materials such as discarded plywood, plastic, cardboard, etc. Subsequently, the five principles that guided the development of the contemporary building system—referred to as the "Clip System"—were that it was efficient, unskilled, mobile, flexible/adaptable, and provide for multi-use. Throughout the development of the Clip System, the updated theoretical principles

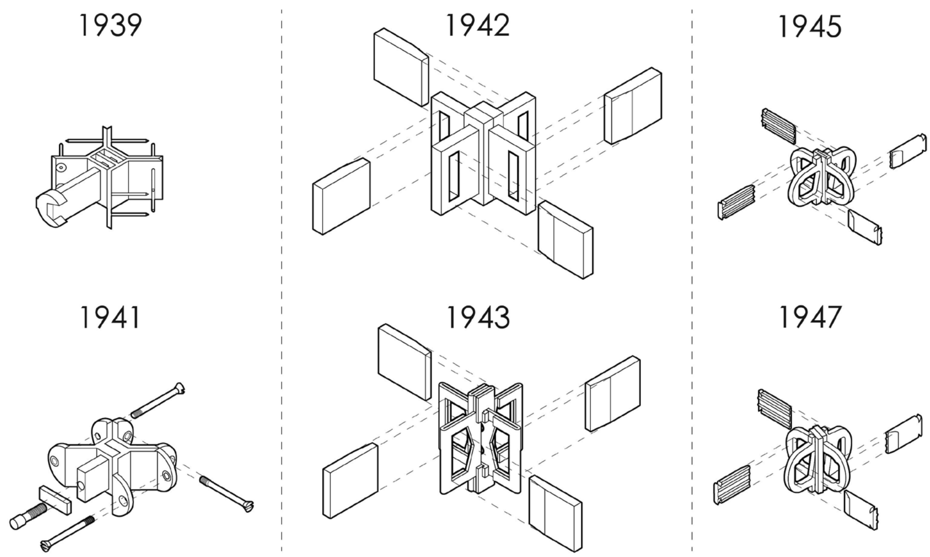


Figure 7: Evolution of the wedge connector over a period of 8 years – as explored through drawings. Source: Author 2018.

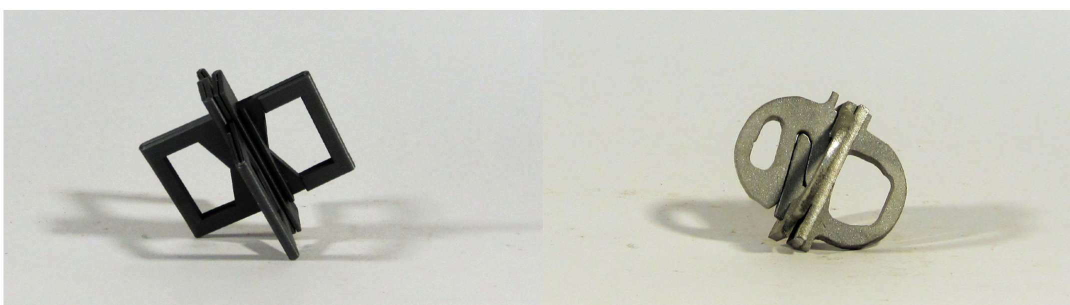


Figure 8: 3D printed and aluminum reproductions of the wedge connector through its evolution supplemented by a drawn analysis. The physicality of the 3D object led to an understanding of it as a precisely designed joint. Source: Author 2018.

of Wachsmann's universal were constantly used to test the development of joints, panels, and associated tooling. If the fabricated iterations, figure 10, of these systems, components were successful, they met all five of the principles derived from Wachsmann's work; conversely, if they were unsuccessful, they did not meet all requirements.

Over the course of two years, the Clip System, figure 11, developed through a dialog between empirical full-scale testing and models and determining their success or failure in dialog with the theoretical principles extracted from Wachsmann's universal. Similar to Wachsmann's methods, this research took a joint-first approach to designing a "Universal Building System". The principles of the universal became theoretical guiding rules for this process of clip evolution, grounding the work with a historical analysis of Wachsmann's work. As the Clip System developed, challenges inherent in designing a universal prefabricated system emerged. However, through the already established dialog between Wachsmann's work and the Clip System, "Wachsmann-ian" solutions were revealed and applied to the work. This resulted in a deeper understanding of Wachsmann's process, but also informed the evolution of a new Universal Building System design.

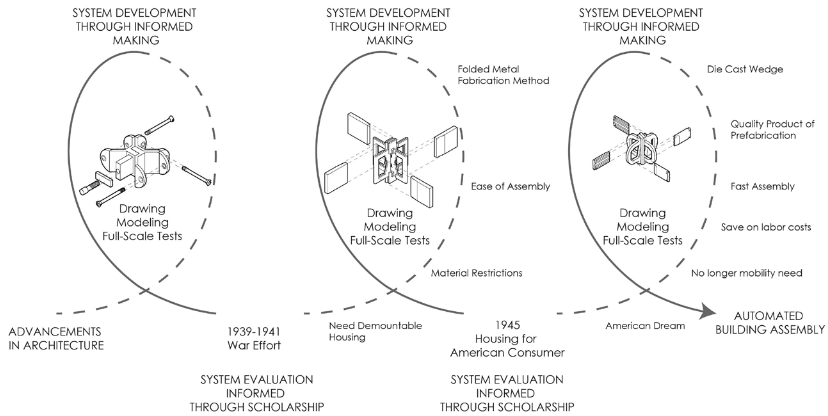


Figure 9: Development of the wedge connector by Wachsmann as a cyclical process of design, full-scale testing, and analysis. Source: Author 2020.

While the clip design informed the required tooling, the clip and node system evolved from Konrad Wachsmann's work, figure 12. Besides the principles of the universal, the assembly sequence and initial desire to produce a system capable of multi-directional assembly generated a unique challenge. Unlike the wedge connector, the Clip System is exposed, rather than embedded within the panel. Though this created new problems such as a gap between panels, it was a decision made to facilitate assembly and disassembly. Before arriving at a design that included an open center, the Clip System developed into a two-part system of clips and nodes. This allowed for panels to be assembled and arranged with one universal clip. The associated panels could be configured in a number of directional ways using one of four different nodes, as seen in figure 13. Initially, the node developed out of a desire to allow for multi-directional assembly; the panels could be set in place in any orientation or direction and then the nodes would simply be slid on top

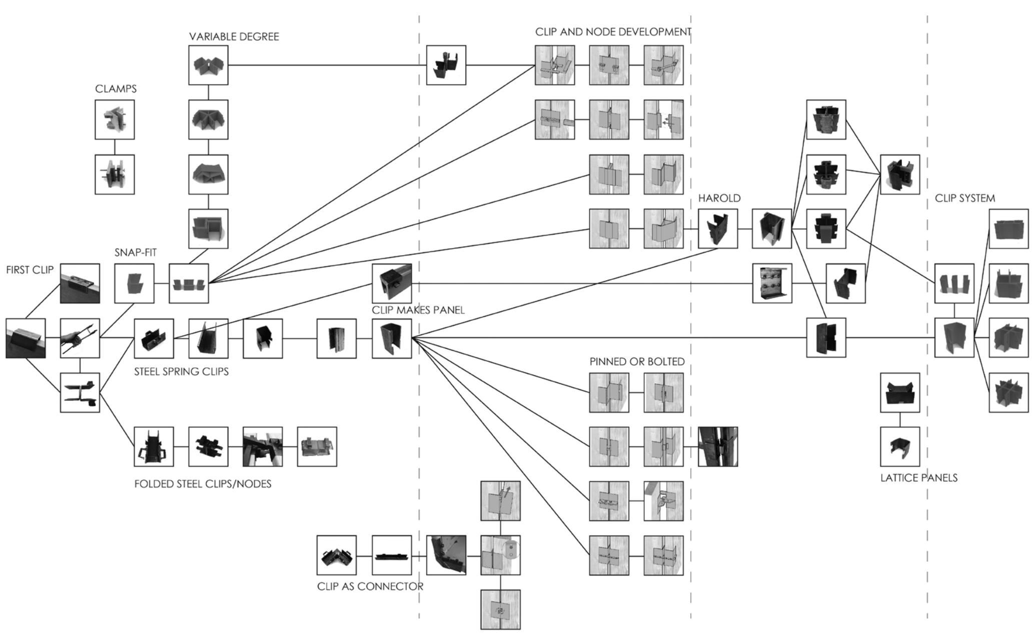


Figure 10: As the Clip System evolved over the course of two years, different lines of evolution worked toward a universal building system based on the principles laid out by Konrad Wachsmann. Source: Author 2018.

Figure 11: These three clip and node experiments explored the differences between the fabrication process for crafting the sliding node through welding, forging, and 3D printing. Source: Author 2018.

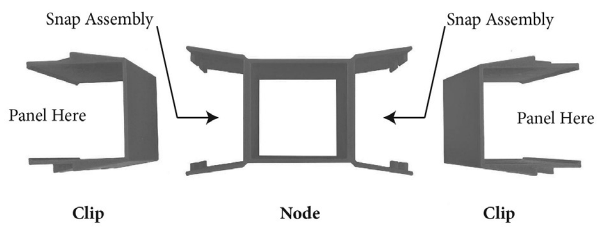


Figure 12: The Clip System is a snapfit system consisting of clips, nodes, and panels. Source: Author 2018.

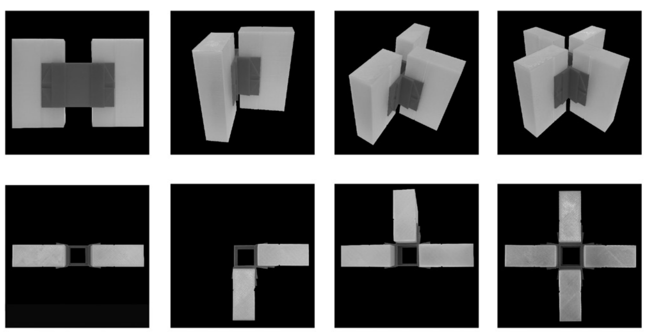


Figure 13: Final iteration of the Clip System includes parallel, perpendicular, three-way, and four-way connections. Source: Author 2018.

locking everything together. Eventually, the concept of a sliding node gave way to a snap-fit design with an open center, figure 14. Again, the solution was based on observations made through replicating and analyzing Wachsmann's work, wherein, ultimately everything has an assembly order, therefore multi-directional assembly is not necessary for the system to be universal.

A fixation on the joint and preliminary full-scale tests assembled from the joint and panel resulted in a small construction that could be assembled by two people in approximately 80 minutes and dissembled in about 40 minutes, figure 15. While this initial test was a successful proof of the concept of the clip, panel, and tool, it revealed the importance of assembly sequence and brought into focus a gap that formed between interconnected panels. When checked against Wachsmann's work, it became apparent that he also emphasized a very specific assembly sequence, one designed into the wedge connector itself. In addition, he detailed the importance of an "open center" in a joint and panel modular system as well as the module where "building elements and joint lines are always identical with the modular planning raster" (Wachsmann 1961, 78). Both of these properties of Wachsmann's universal building system "appeared" serendipitously in the system developed by the author.

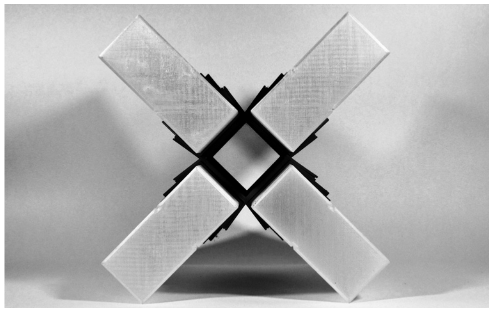


Figure 14: The open center of the clip system node is exemplified in this four-way connection. Source: Author 2018.

In the summer of 2018, a member of the research team participated in the Bauhaus Research Lab "The Art of Joining: Designing the Universal Connector" and contributed to an exhibition of findings resulting from the lab. The informed design and fabrication of the exhibition components acted as further proof of the importance of module, open center, and assembly sequencing in a universal system. In the spirit of Wachsmann, the exhibition structure used panels with a 1:3 proportion in a modular system, figure 17. Connectors were inserted into the edge of these panels to keep the center of each joint on the open center of the module. The module that included an expressed open center as a gap actually facilitated the success of the concept. This type of system made assembly quick and easy. The exhibition work proved that there are many types of systems that can be generated from a standard set of rules or templates for a universal building system as laid out by Wachsmann's work. In this case, a kind of Universal Exhibition Structure facilitated the construction of spatial organizers with horizontal and vertical panels, while maintaining alignment to a grid turned 45 degrees in the gallery. Like Wachsmann's system, this system contained only four types of connections: parallel, perpendicular, three-way, and four-way orthogonal connections.

In the summer of 2018, a member of the research team participated in the Bauhaus Research Lab "The Art of Joining: Designing the Universal Connector" and contributed to an exhibition of findings resulting from the lab. The informed design and fabrication of the exhibition components acted as further proof of the importance of module, open center, and assembly sequencing in a universal system. In the spirit of Wachsmann, the exhibition structure used panels with a 1:3 proportion in a modular system, figure 17. Connectors were inserted into the edge of these panels to keep the center of each joint on the open center of the module. The module that included an expressed open center as a gap actually facilitated the success of the concept. This type of system made assembly quick and easy. The

Figure 15: Full-scale assembly test of Wachsmann-based modular system. Source: Author 2018.

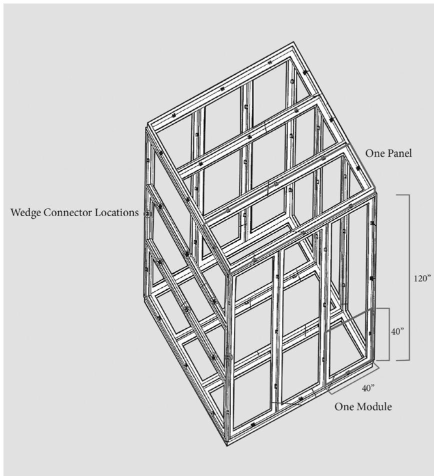


Figure 16 (left): This diagram shows Wachsmann's Packaged House System panel module and wedge connector locations. Source: Author 2018.
Figure 17 (right): Bauhaus Lab 2018 Exhibition of Findings "The Art of Joining: Designing the Universal Connector", demonstrates the success of Wachsmann's Modular System. Source: Author 2018.

exhibition work proved that there are many types of systems that can be generated from a standard set of rules or templates for a universal building system as laid out by Wachsmann's work. In this case, a kind of Universal Exhibition Structure facilitated the construction of spatial organizers with horizontal and vertical panels, while maintaining alignment to a grid turned 45 degrees in the gallery. Like Wachsmann's system, this system contained only four types of connections: parallel, perpendicular, three-way, and four-way orthogonal connections.

DISCUSSION & CONCLUSION

The dialog between Wachsmann's universal joint and the development of the Clip System supports an architectural methodology based on modeling, reproduction, and prototyping, in conversation with historical significance, scholarship, and theory as a means of pursuing when performing architectural research. This method can be utilized by students, researchers, and practitioners as a method for analyzing/re-engaging historical work and applying it to a contemporary context. The methodology discussed in this paper provides a useful method for leveraging the theory, successes, or failures of historical precedents against contemporary requirements of a specific problem. This paper describes an example of this methodology which utilized an iterative process of informed-making-based research to explore Konrad Wachsmann and the Packaged House System and led to a deep understanding of this historic precedent or prefabricated housing. If a research method of modeling, reproduction, and prototyping alone had been utilized, without critical observations about the theory of Wachsmann's work, the (uninformed) artifacts would not have had as much significance.

Making, the hand, a tactile connection to materials, parts, and building elements constitutes an intelligence that parallels one situated in the mind. Students of architecture and other design disciplines can employ prototyping/modeling as a research tool by using the process of informed-making to interact with, support, and enlighten historical analysis, and comparison, in a continuous dialog. In conclusion, an architectural methodology for research that creates a dialog between making and theory can lead to a deep understanding of architecture, building materials, and insight into the application of new discoveries to contemporary problems.

REFERENCES

Andrzejewski, E. 2018. "The Wedge Connector: From Function to Symbol." In *The Art of Joining: Designing the Universal Connector.* edited by P. Denny and A. Przywara, 21-30. Leipzig: Spector Books.

Bollinger, J., and X. Mendoza. 1971. "Location Orientation Manipulator: A Physical Tool for the Study of Kinematics of Assembly of Building Structures" [PhD diss.], University of Southern California.

Burry, M. 2012. "Models, Prototypes and Archetypes Fresh Dilemmas Emerging from the 'File to Factory' Era'," in *Manufacturing the Bespoke: Making and Prototyping in Architecture*. edited by B. Sheil. Chichester: Wiley

Kieran, S. 2007. "Research in Design: Planning Doing Monitoring Learning." *Journal of Architectural Education* 61(1), 27-31.

Sabatto, S. 2012. "Des clavetages aux coins : l'optimisation de l'ou- vrabilité des systèmes constructifs conçus par Konrad Wachsmann durant la guerre froide sous la supervision des agences gouvenementales américaines; From Keying to Wedging: the Optimized Workability of Constructional Systems Designed by Konrad Wachsmann During the Cold War Under the Supervision of the North American Governmental Agencies," In *Architecture industrialisée et préfabriquée: connaissance et sauvegarde; Understanding and Conserving Industrialised and Prefabricated Architecture.* edited by F. Graf and Y. Delemontey, 169-185. Lausanne: Presses polytechniques et universitaires romandes.

Wachsmann, K., and W. Gropius. 1943. Sectionalized Construction for Temporary Dwelling Units, National Housing Agency, Federal Public Housing Authority, Type T.D.U.-1. New York City, NY: General Panel Corporation. Harvard Art Museums, Somerville Research Facility.

-----------. 1944. *Prefabricated Building*. U.S. Patent 2,355,192 filed May 30, 1942 and issued August 8, 1944.

-----------. 1947. *Building Structure*. U.S. Patent 2,421,305 filed August 10, 1945 and issued May 27, 1947.

Washmann, K. 1961. *The Turning Point of Building: Structure and Design*. New York, NY: Reinhold Publishing Company.

-----------, K. 1965. *Building Research Division: Organization Equipment Programing*, Chart 7-8. University of Southern California. Architecture Archieves, Akademie der Künste.

-----------, K. 1980. Timbebridge 1901-2001, Konrad Wachsmann: An Autobiography [Unpublished Manuscript]. *Architecture Archives, Akademie der Künste.* Berlin.

-----------, K. 1995. *Building the Wooden House: Technique and Design.* Berlin: Birkhäuser Verlag.

Ward, R. Jr. 1972. "Konrad Wachsmann." *AIA Journal* 57(3), 34-42.

Witt, A., and C. Reznich. 2018. *The Natural Forces Laboratory*. Ralph Knowles and the Instrumentalized Studio.