Reconstructing Antiquity: Interpreting Ancient Architecture with Computational Simulation Tools

Tim Frank[1]

[1]Kennesaw State University, Atlanta, GA

ABSTRACT: This paper presents a new approach to archeological reconstruction, utilizing state-based building performance simulation (BPS) tools to compare regressed climate data and architectural features unearthed during field excavation. In the archaeological discipline, where reconstructions of architectural systems are routine, no applied methodologies have been established that highlight the use of state-based BPS tools as a complimentary track to culture-based forms of interpretation. To address this shortfall, this paper offers an overview of a BPS enhanced workflow that prioritizes trial and error experimentation, enriched by the systematic observation of building-environment relationships that are fundamental to early dwelling patterns. The workflow consists of four primary phases: (1) the integration of archaeological datasets within an interoperable modeling domain; (2) the introduction of input states into the domain with subsequent state-change observation; (3) the corroboration of simulation output across multiple analysis types; and (4) the reiteration of various building configurations. The interaction of the base modeling platform and the simulation plug-in components within a common interface eases the swift instantiation of reconstruction alternatives from output acquired using state-based lighting, radiation and fluid dynamics domain branches. The observed behavior of light, heat and airflow patterns within the simulation domain invite incremental revisions to virtual models that test their probability with respect to the maintenance of human health described in ancient treatises. The paper provides an in-depth description of each workflow phase and demonstrates their functionality using case studies from classical sites in ancient Asia Minor including Miletus, Priene and Pergamon where structures currently exist in an incomplete state. While much can be understood about these building systems from even meager archaeological records including building location, ground integration, structural configuration and spatial disposition; new knowledge about how early populations organized space around the dictates of climate can be elicited using BPS tools.

KEYWORDS: ancient architecture, computational simulation, experimental archaeology, environmental design, virtual reconstruction

INTRODUCTION

Architectural anastylosis is a reconstruction method used in archaeology to restore a ruined building from its fragmented remains, in its original location, to the most comprehensive degree attainable. In a broader sense, architectural reconstruction in the field of archaeology is a preservation practice used to return a building in ruin to an earlier and more complete state (ICOMOS, 2013). This restoration practice includes graphic forms of illustration and visualization that traces back to the fifteenth century and the likes of Alberti who included recommendations and instructions for the study and the visual restoration of ancient buildings (Salmon, 2003). The purpose of these efforts, as they progressed into the sixteenth century, by architects including Palladio and Raphael was to methodically document ancient buildings that were being steadily destroyed during this period (Brothers, 2001). However, in the nineteenth century, architects including Ruskin were critical of this approach due to the stylistic embellishments introduced by interpreters that tended to diminish the weathered character the building had attained over its lifetime (Stanley-Price, 2009). Even today, there is ample criticism of this approach due to the lack of concrete evidence surrounding the configuration of ancient buildings in their complete state that would be required to finalize preservation. Additionally, physical preservation presents risks related to further damage of architectural antiquities with attempts toward on-site anastylosis (UNESCO, 1976). However, with the emergence of digital technology within the archaeological reconstruction process, virtual reconstructions are now possible to offset the risk of further damage to ancient sites.

Developments in archaeological digital survey methods and remote sensing in recent decades have aided the advancement of three-dimensional reconstruction modeling, resulting in an acceleration of archeological interpretation and an increased understanding of archeological datasets (Forte, 2016). The ability to conjoin datasets pertaining to building and environment in a shared modeling domain is especially pertinent in ancient building reconstruction where building models can be born directly from correlations made between climatic states and boundary configurations. This approach is particularly useful in situations where architectural evidence is meager and additional data is required to underpin working interpretations of past building configurations. Furthermore, drawing comparisons between building and climatic datasets approximates that act of sheltering in place, which is one of the founding principles of architecture, to protect inhabitants from extreme elements, especially the weather (Rapoport, 1979). Furthermore, if early dwelling patterns are understood as an orderly network of relationships between people and place, a reliable architectural reconstruction methodology necessitates a synergistic approach that permits the observation and measurement of these fundamental relationships.

When prioritizing a synergistic approach to architectural reconstruction, BPS tools are well suited to support the process through their hypothesis testing potential on one hand and through a domain that is capable of emulating early dwelling environments on the other. In recent decades, experimental archaeology has emerged as a testing procedure used to replicate ancient processes in order to learn more about how early societies coped with the world around them (Outram, 2008). The method is particularly useful when there are large gaps in data pertaining to how people built in antiquity as it adds a valuable layer of evidence that can help strengthen interpretations generated by more conventional modes of analysis (Hostetter, 1994). This approach also incorporates hypothetico-deductive routines as well, which permits the team to develop a hypothesis stemming from reliable datasets, test it through modes of reconstruction, and evaluate the outcomes against the original assumption (Barton, 2014). While this process is used to physically reconstruct buildings on projects of archaeology, digital modeling and simulation platforms enable researchers to conduct similar investigations virtually. The usefulness of digital technology in reconstruction is further reinforced through its support of 'optioneering', where numerous building configurations can be digitally modeled and tested to better understand boundary-state interactions while using iterative testing protocols to strengthen working interpretations (Marsh and Khan, 2011). This trial and error form of experimentation is enhanced through the mathematical replication of physical real world phenomena by simulation tools in applying physical conservation laws to approximate the behavior of light, heat and airflow within constructed environments (Augenbroe, 2003).

1.0 BACKGROUND

The core of state-based BPS analysis is the technical domain comprised of digitally modeled building boundary configurations, input states taken from regressed climate data and mathematical equations used to calculate the behavior of environmental factors within the built environment. Building boundary and environmental state interactions tested and observed within the modeling domain disclose the relative effectiveness of proposed building reconstructions in moderating climatic extremes for the well-being of inhabitants. Literary sources translated from antiquity serve as the basis for performance benchmarking that outline the impact on human health by development decisions at both urban and building scales. Therefore, the acquisition of three major data sources prior to the commencement of the simulation supported architectural reconstruction process appropriately situates the study in relation to reliable building, climate and cultural data.

A central part of the archaeological record, acquired through field survey and excavation, includes building data. Archeological survey entails the examination of areas in the field through observation of surface level features and the use of remote sensing equipment to determine the nature of subsurface building signatures. While survey methods make no disturbance and leave no physical traces in the field, excavation is a more invasive approach, where archaeologists systematically remove horizontal layers in a given area to collect the maximum amount of information. These highly scrutinized activities require permits by the host country's ministry of culture and require meticulous care by experts trained in the area. Thorough drawings, photographs and notes are kept during excavation that describe the three dimensional nature of features uncovered and constitute the architectural record reported on in detail at the conclusion of each field season. Outcomes from these activities can be viewed on-site if the site is well preserved and managed by the local ministry, in museums dedicated to the archeological site in addition to the yearly publication of results by the archaeological field team. For the sake of accuracy, carefully vetted building element representations generated by permitted field teams maintain precision as many inaccurate representations of ancient structures are in circulation today. In the example provided below, portions of three Classical and Hellenistic sites in ancient Asia Minor are depicted: Miletus, Priene and Pergamon, all of which were surveyed and excavated under the auspices of the German Archaeological Institute that serve as the basis for all reconstructions cited and presented below (FIG. 1).

Climate data, a relatively new dataset on projects of archaeology, is acquired from local monitoring stations and is logged over many years to determine the microclimatic patterns present on excavation sites. Since weather patterns shift in a span of centuries, the science of paleoclimatology has emerged to examine climate change across millennia. Reconstructions of earlier climatic states occur through the study of natural elements like ice, tree rings and fossils that serve as proxies and extend our knowledge of climate patterns across thousand-year periods when compared against weather data logged today.

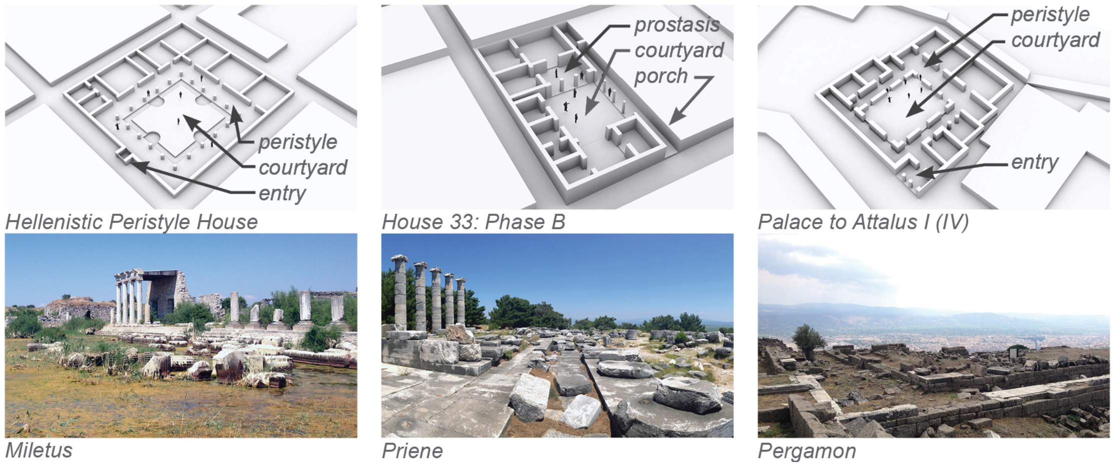

Figure 1: Foundation reconstructions above and site photos below. Source: (Frank 2015)

The case studies highlighted in this paper all reside in western Anatolia, also known as ancient Asia Minor, and share a similar temperate macroclimatic profile with hot, dry summers partnered with cool, wet winters. Variability has been noted in the region over the course of three millennia with shifts in temperature levels and precipitation rates (Bryson et al., 1974). However, wind patterns are considered stable in these climate reconstructions across this three thousand-year period. These findings are consistent with correlations between ancient sources and climate data logged in the same province today that describe strong northerly winds, named Boreas, bringing cold temperatures and moderate winds out of the west, named Zephyros, supplying warmer temperatures (*Theogony 870; Iliad 9.5; Odyssey 5.295*). Meanwhile, mild variations in the earth's orbital tracking around the sun in one-hundred-thousand-year phases, lead to negligible shifts in solar path across the span of three millennia. Asia Minor is located along the western coastline of modern-day Turkey and resides 38 degrees north of the equator and 27 degrees east of the prime meridian. From the winter to the summer solstice, the sun's altitude angle in Asia Minor changes from 27–74° when measured at noon.

While the modern practice of architectural design defines standards for occupant comfort and well-being using quantitative benchmarks, acutely measured with portable instrumentation and simulation tools; they were depicted in a qualitative manner in antiquity. Recommendations regarding the built environment's impact on human health emerged in the 5th century BCE in Asia Minor through the writings of Hippocrates, a physician practicing during the Classical period. His treatise on the subject titled, "Air, Waters, and Places" describes the impact of climate on human society and makes recommendations for how urban microclimates influence the health of inhabitants (Hippocrates and Adams, 1881). Solar exposure is factored relative to cardinal orientation, rising from the east, setting to the west and most influential at midday where exposure is recommended to combat disease in moderation for structures that orient to its southerly orientation. The configuration of structures should account for prevailing wind directions; where irregular southerly hot winds blow should be tempered, strong northerly cold winds should be prohibited, a westerly humid wind from the Aegean should be moderated, and healthy easterly winds should be admitted. Houses in the period are described as largely enclosed to protect inhabitants from the wind, rain and snow while rainwater is depicted as being light, sweet and clear for consumption. Together, these recommendations play an important role in the analysis, as fitness criteria for simulation outcomes, used to evaluate the effectiveness of structures to moderate environmental factors in accordance with occupant well-being.

2.0. METHODOLOGY

The initial stage of the workflow consists of importing drawings from the archeological record into the interoperable modeling domain where they are scaled and traced over using vector contours. These traces serve as the regulating armature for NURBS surface construction and eventual translation into closed watertight poly-surfaces. It is crucial at this stage to trace the record plans accurately as they likely serve as the only remaining physical vestiges of the building. The first reconstruction model should reflect what remains on-site, which in the case of buildings from the Classical and Hellenistic periods in Asia Minor, would consist of foundation systems, floors and entry thresholds since stone was the predominately-used building material. Once modeling concludes of building remains and surrounding areas, the systematic tracking of additions or subtractions to the model commences as this practice enters into the realm of speculation whose outcomes cannot be known with absolute certainty. It is also important at this stage of modeling to use simplified representations of the structure as superfluous information can lead to unnecessary demands on computational resources.

After the initial building configuration is digitally reconstructed, the workflow shifts to the second stage where plugin simulation programs migrate to the modeling domain and input states are assigned. Again, input states stem directly from the writings on climate and health in addition to regressed weather data. Once simulations are run, researchers observe the change in environmental states that result from interaction with building boundary configurations within the shared domain. The digital process emulates the way ancients would have moderated climatic factors in order to maintain well-being, according to text from those like Hippocrates writing at the same time. Therefore, the evaluation of output states within a simulation domain is framed relative to these ancient recommendations in order to partner interpreted building outcomes with presumed intent during the same period. Using multiple simulation branches enables the synergistic study of buildings where boundaries can be evaluated relative to numerous environmental factors within the same domain.

The third stage of the process examines possible synergies in the reconstruction model, which in this example, is the interaction of multiple physical substances whose outcome provides greater impact than the summation of individual parts. While simplified simulation tests reduce analysis time, they also allow researchers to narrow the scope of analysis, focusing on relationships between individual building parts and their effect on environmental states. However, comparing and contrasting results from within the more extensive domain facilitates a systematic understanding of how individual building elements satisfy a number of environmental factors, bringing the polyvalent or synergistic aspects of the building to light. Moreover, reiterating simulation routines within one branch brings result corroboration to the fold, where non-expert users can gain confidence in simulation outcomes, especially when results from one test verifies the results from another.

However, there are limitations to this approach, knowledge that the research methodology just cannot elicit. Because evidence of buildings and cultural heritage in antiquity is so sparse and poorly preserved, we cannot draw absolute conclusions about the reconstructions produced nor the environmental states represented in these virtual domain models. While this caveat may prove prohibitive for many researchers, the process does shed valuable light on how early societies organized space in relation to their environment. Instead of focusing on singular solutions that would be impossible to validate, the workflow prioritizes alternative reconstructions to strengthen working interpretations generated by more established protocols in the field. This leads to the fourth stage of the process where the building geometry is transformed within the modeling domain to examine how these alterations result in state change within the surrounding area of influence. The pluralism enabled by digital technology in partnership with a stable domain configuration can support this form of analysis, incremental change resulting in an incremental understanding of state-boundary relationships. It is at this stage that an improved understanding of these first-principles relationships are compared to datasets outside the domain either on the same archaeological field project or on others developed during a similar period in the same region.

3.0. CASE STUDIES

This paper demonstrates the functionality of the presented workflow using case studies from portions of three Classical and Hellenistic settlements located in ancient Asia Minor including, Miletus, Priene and Pergamon whose building remains are incomplete. A family of peristyle building types have been selected to test the response of this building type to its climate profile, to ascertain why the building configurations proposed in regional reconstructions to-date share such similar characteristics, and how building simulation tools can offer new layers of information to this well-established discourse. The courtyard house was the prominent dwelling type in urban communities with a peristyle or colonnade surrounding a central courtyard that supplied access to enclosed perimeter rooms. The court in Classical and Hellenistic schemes was an indispensable feature that supplied natural light and air to all rooms of the house while doubling as a collection point for rainwater (Schoenauer and Seeman, 1962).

3.1. Miletus

Once a harbor city, Miletus was one of the most prominent Greek settlements prior to the 5th century BCE whose plan was designed by city native Hippodamus consisting of a grid plan that was inspired by geometrically designed settlements (Bayhan, 1998). The urban plan contains houses on individual blocks created by rectilinear street networks occupied by late period peristyle courtyard houses, each approximately 100 feet by 120 feet in size. A Hellenistic peristyle house adjacent to the North Agora is digitally reconstructed after Schleif to include a central court, surrounding peristyle and enclosed rooms on the northern edges of the compound to buffer cold winds indicated in ancient descriptions. Analysis indicates ample light and air access through the courtyard with moderate to low light and air velocity levels in the surrounding spaces (FIG. 2). Openings introduced along the outer and the inner walls of the compound along with additional ventilation chases through the roof promote increased air velocities in surrounding rooms along with higher light levels in enclosed spaces. Simulation analysis reveals little change in openings along the outer wall, demonstrating the value of the central court when securing compound perimeters while ventilation chambers provide the most impact drawing fresh air from the central court through the surrounding spaces (FIG. 3). Reconstruction alternatives of the roof structure over the enclosed rooms could examine how light and air sourced from the central courtyard could be drawn at higher velocities through enclosed areas while exhausting smoke from internal heating sources during the winter.

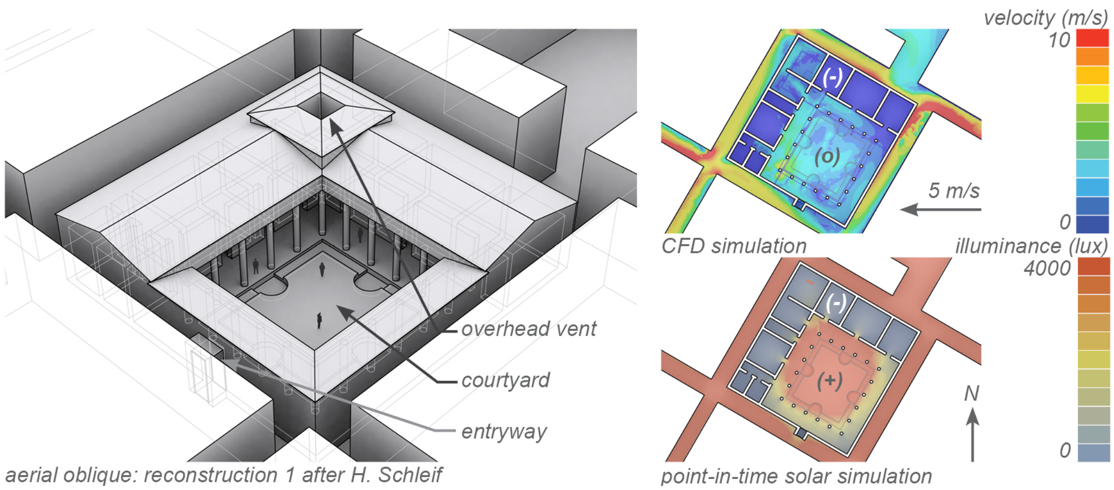

Figure 2: Miletus reconstruction #1 after H. Schleif. Source: (Frank 2017)

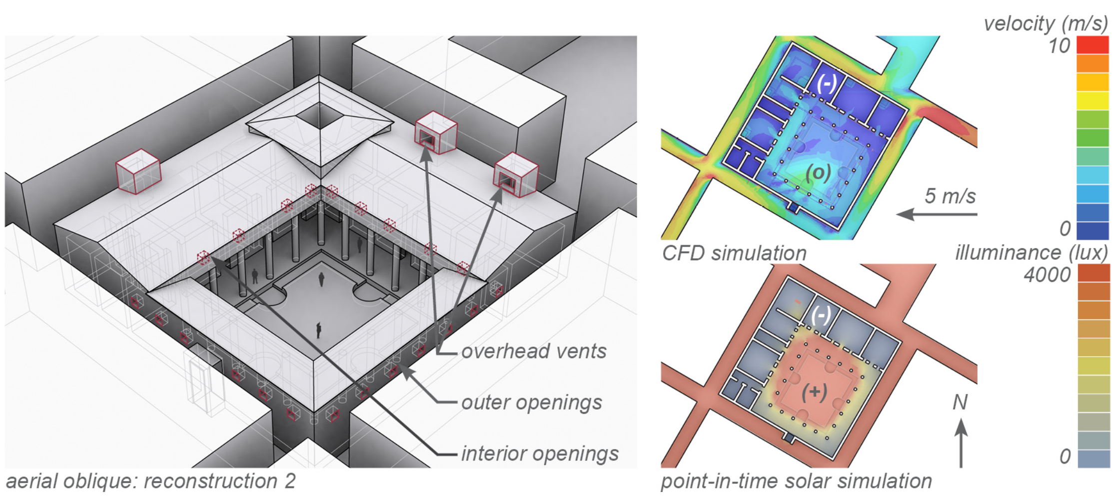

Figure 3: Miletus reconstruction #2. Source: (Frank 2017)

3.2. Priene

Priene was also once a harbor city and organized using the Hippodamian grid system, experiencing its most prosperous period during the sixth century BCE. In this application of the ancient planning system, the planning grid orients in the cardinal directions enabling the buildings situated within each block, also known as insulae, to orient directly south to benefit from solar access (Dontas and Ferla, 2006). A structure of 60 feet by 100 feet within a typical block of 114 feet by 154 feet, Phase B of House 33 in the Western Residential Area is reconstructed after Krischen. The house includes a central court with prostas, or vestibule, opening to the south that together harvests abundant solar gains with moderate access to fresh air (FIG. 4). Openings are introduced in the northernmost enclosed rooms overhead to draw air sourced from the central court while increasing illuminance rates for spaces separated from the prostas and court. Simulation analysis indicates little light and airflow increases from small sidewall apertures but moderate upsurges in both light and air velocities for southward oriented clerestory openings (FIG. 5). Additional reconstructions would explore how shifts in roof height partnered with multiple levels could accommodate clerestory openings oriented to the south that would illuminate the northernmost spaces in the complex while promoting natural ventilation throughout.

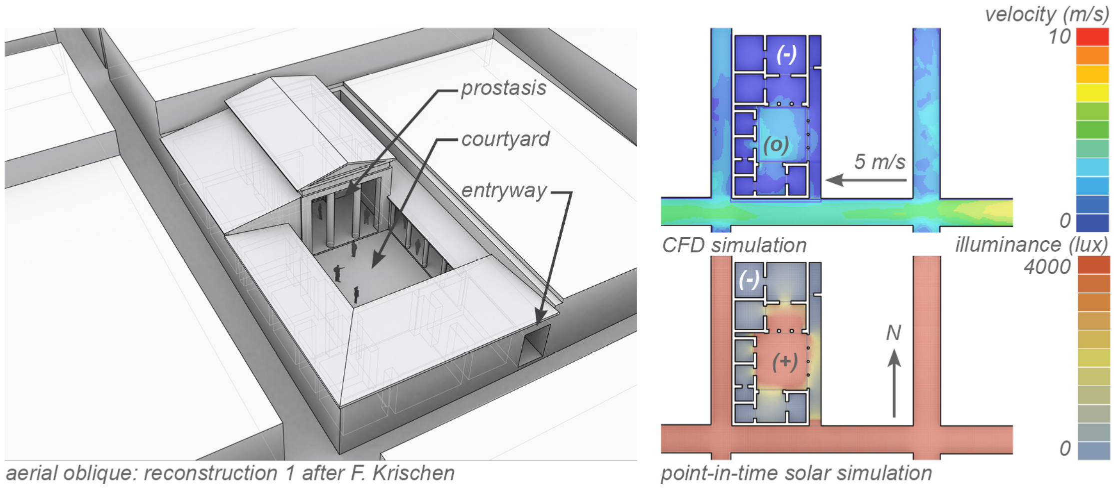

Figure 4: Priene reconstruction #1 after F. Krischen. Source: (Frank 2017)

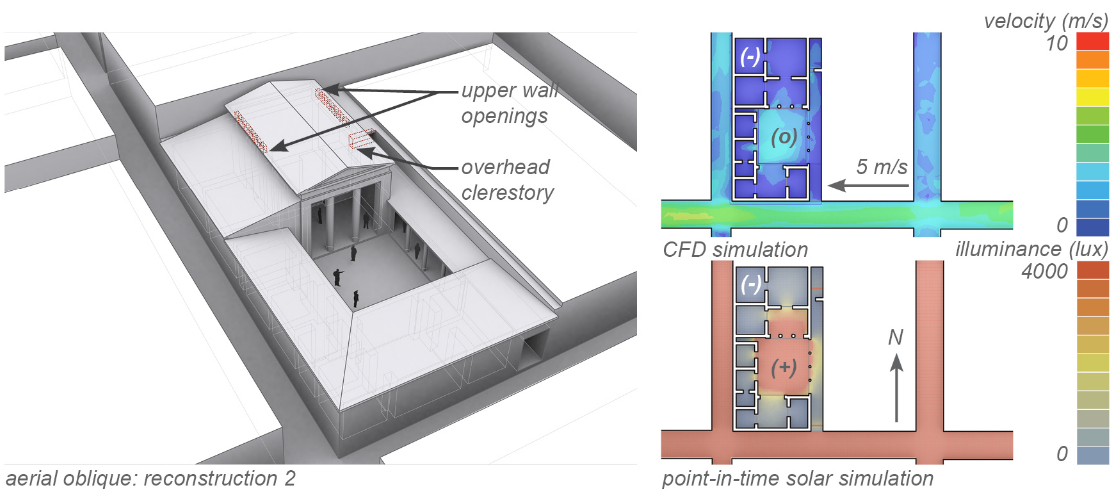

Figure 5: Priene reconstruction #2. Source: (Frank 2017)

3.3. Pergamon

Pergamon, situated inland, a few kilometers from the coast was a city whose acropolis was perched atop the southern face of a naturally protected promontory serving as a capital city beginning in the third century BCE. (Pirson and Scholl, 2014). While planning in this city was more organically derived, the palace complexes, which were organized in the peristyle form, lined the northern edge of the upper acropolis and began the cascading of terraced plinths down the slope, each supporting civic structures including the library, stoa and upper agora. The Palace to Attalus I (IV) is reconstructed after Schleif to include a central court equipped with rainwater cistern, a largely enclosed passageway surrounding the court serving enclosed perimeter rooms. While ample light and air access is indicated in the open court, the surrounding spaces show limited access to natural resources likely due to the multi-level structure and the high degree of enclosure around the courtyard suggested by the reconstruction (FIG. 6). In the second reconstruction, the area defining the central court loosens with the introduction of a slender colonnade while the easternmost block of rooms are outfit with new openings overhead. These alterations produce increased light levels in the passageway and the rooms that encircle the central court while the easternmost openings promote additional ventilation rates in the eastern half of the palace complex (FIG. 7). With the height of the easternmost area in the initial reconstruction geometry partnered with its fortified plinth, added levels of permeability for this section of the complex could be explored to source higher amounts of fresh air and natural daylight to some of the deeper rooms in the palace.

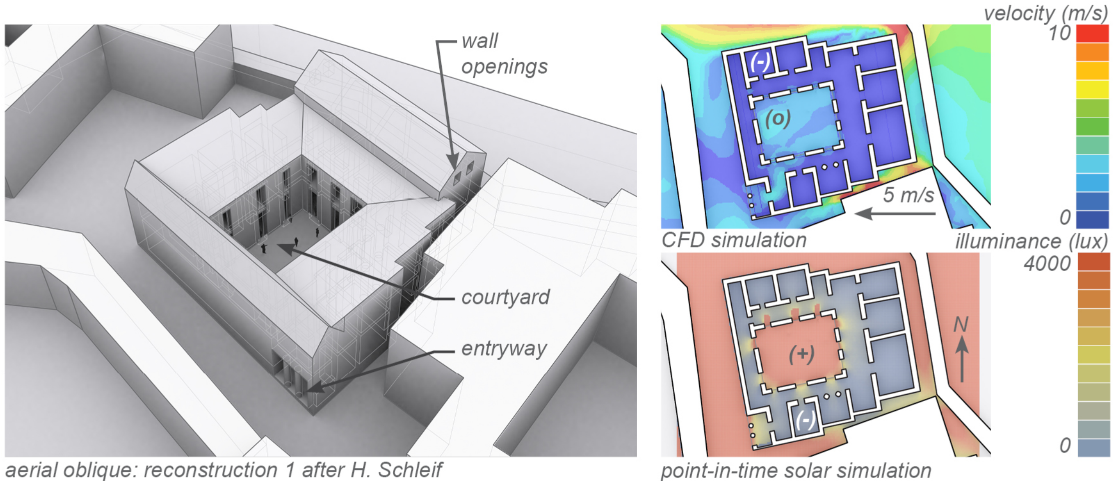

Figure 6: Pergamon reconstruction #1 after H. Schleif. Source: (Frank 2017)

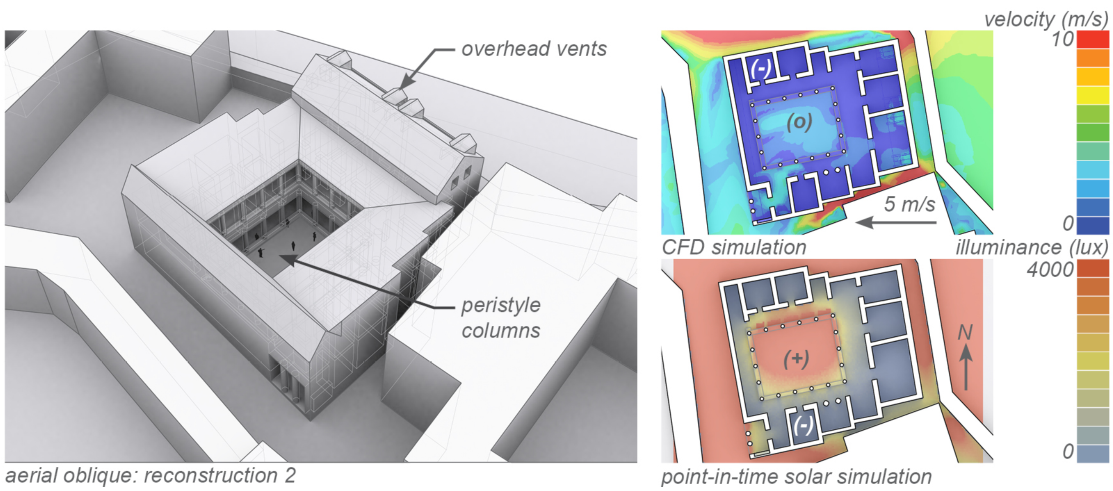

Figure 7: Pergamon reconstruction #2. Source: (Frank 2017)

CONCLUSION

The results from this workflow contribute to our understanding of how humans could have persisted through climatic extremes using constructed systems in the first millennium BCE. The workflow also offers emerging technology-enriched methods to engage the large repository of building knowledge that remains latent at classical archaeological sites. The process compliments deductions drawn from cultural sources and offers fresh insight to archaeological analysis by introducing climate data to the ongoing discourse, comparing this new dataset to existing material finds using well-established scientific methods that emulate physical states from laws of conservation. However, simulation tools and the outcomes they produce are not panaceas. The method does not aim to bring value judgments to the process of reconstruction, evaluating outcomes in absolute terms, the basic process aims to diversify our understanding of ancient building systems through new forms of data and methods of comparative analysis. While this process is still in the nascent stages of development, the need for improvements have been noted including the need for a central platform that would host and gather all digitized archaeological datasets collected in order for interpretative trajectories to be better informed through comparison and corroboration. To set the stage for these improvements, next steps in this research include further engagement of the presented case study areas, expanding upon work in the result corroboration phase by introducing additional state branches to the process for comparison. Furthermore, next steps also include extending the geometric reiteration stage of the process, continuing to propose reconstruction alternatives in critical areas to understand incrementally how ancient building typologies, like the peristyle court, had likely moderated the extensive environment.

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