Critical WikiHouse: Connecting GIS data to site and tiny home design.

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ABSTRACT: The construction industry is one of the largest consumers of natural resources in the world, being responsible for 50% of the carbon emissions recorded since the 1950's (Adriaanse et al.,1997). While the information age has brought us tremendous amounts of environmental data and design computational ability that can be leveraged to create advanced sustainable design solutions in architecture, the dissemination and implementation of the tools and techniques of sustainable design are limited to a small fraction of the construction industry with architects designing only 2% of the total building construction worldwide (Parvin 2013). With the world population projected to rise by billion in the next 15 years, mass sustainable housing systems are going to play a crucial role in achieving sustainable development (Gerald 2014). This research suggests that the increasing availability of environmental data, combined with the ease of access to powerful computational capabilities and low costs of customized digital fabrication are the modern resources that can direct architecture in a way that is environmentally stable, resource conscious and ultimately sustainable. The research examines open source and easily accessible methods of employing these resources, connecting GIS data to BIM systems to create customizable design solutions optimized for sustainable development. [1]

This paper focuses on the application of environmental data and the adaptation and expansion of an existing open source WikiHouse platform. Currently it is a global, open-source, digitally de-centralized small home system, which is fairly autonomous; i.e., it has few connections to its specific environment and site. It can be customized for size, but lacks the ability to leverage environmental data for optimized form modifications. The research adapts this system to various natural forces and conditions, creating a new wiki design methodology, which incorporates various open-source inputs to create a more sustainable, adaptive design solution that responds to natural environmental conditions.

KEYWORDS: Digital fabrication, Grasshopper, Geographic Information Systems, WikiHouse, Sustainability

INTRODUCTION

The existence of humans is a short blimp on the chronology of the planet, but in our short time here the we have had a tremendous impact on the ecosystem of the planet, comparable to massive geological events, prompting some scientists to declare that we have entered the Anthropocene, a new unique geological epoch marked by the striking acceleration since the mid-20th century of carbon dioxide emissions and sea level rise, the global mass extinction of species, and the transformation of land by deforestation. We are currently at the highest carbon content in the last 800,000 years (World Metrological Organization, 2017) with a rate of species extinction that is comparable to mass extinction events (Ceballos et al. 2015) Recognition of impending problems has existed since the time of the great acceleration of the 1950s, marked as the beginning of accelerated resource consumption by humankind that has led to global climate concerns, but this is the first time in our existence that we have that ability to address the issues pragmatically with a collective intelligence as a species without borders. There is for the first time enough empowerment of information, open source knowledge sharing and data computational capability to propose a framework for a resilient, sustainable development that encompasses human, wildlife and ecosystem preservation and restoration with adaptive evolutionary technologies at a widespread scale.

While upcoming large scale commercial projects, with access to research and development in sustainable design and incentivized by green building initiatives, are beginning to make a headway towards sustainability, majority of the residential sector, being largely either self-built or developer driven construction i.e. without a direct connection to the academic or professional sustainable design and architecture community, has yet to adopt the more progressive tools and techniques of environmentally sensitive design available today. This issue escalates when we consider the need for housing to accommodate our growing population and the limited reach of progressive architects.

The changing landscape of ownership of data in recent years has fostered a new collaborative and openly shared outlook to information, with models of aggregated data collection such as WIkipedia and Google Maps being prime examples. The information age has also brought us a tremendous collection of environmental data, a lot of which is freely accessible or 'open source'. We are constantly recording and logging information from satellites, sensors and aggregators; the scope of data collection is growing rapidly and will continue to grow as technologies become more efficient, affordable and prevalent (Moore's Law). This data, combined with the ease of access to powerful computational capabilities and increasing low costs of customized digital fabrication has made sustainable design a lot easier to achieve than it has been in the past. This will at some point, push the residential construction industry into the age of sustainable development, whether by a bottom up or top down process. At this point we are limited by the sphere of influence that environmental design has in the construction industry. Hopefully soon with the help of technology we will be at a tipping point in architecture where design starts to break barriers of reach, coupled with a general rise in awareness and demand for sustainable, resilient and environmentally sensitive design.

1. ARCHITECTURE OF THE ANTHROPOCENE

Human beings are the predominant force affecting change at a planetary scale, the evidence for this is ample and undeniable. The graphs of change in virtually any parameter that matters for human wellbeing; carbon dioxide, nitrous oxide, methane, deforestation, land degradation, loss of species, have all entered a period of accelerated change post the Second World War (Rockstrom 2010). The rampant use of resources has rendered an unprecedented pressure on earth systems at a scale that climate scientists warn is causing irreparable harm to the stability of earth systems (Filperin 2006). The good news is that we are perhaps the first generation of humans to have the scientific data to be informed that we are undermining the resilience and stability of human life on this planet, and also the first to possess the computational and manufacturing capability to design to mitigate these risks. We are now perhaps in the most critical and exciting phase of human existence-a time when the choices we make will decide the longevity of mankind on this planet.

We should all be aware of the challenge that stand before us, and it's only prudent that one of the largest consumers of natural resources, the construction industry, takes united and drastic measures to combat the environmental challenges we face, and do so in a collective and accelerated pace. This research explores the modern technologies available to architecture and design in an effort to create an openly shared framework for sustainable residential housing that leverages digital design and fabrication to respond to available environmental data.

1.1 Collective Design

Collaborative knowledge aggregating projects have begun to change the way data is accumulated and compiled.

Projects such as Wikipedia exemplify this system with a large number of users contributing to write a modern encyclopedia of articles in a method that is largely peer reviewed and self-rectifying, with over 44 million articles in 287 languages, the English language Wikipedia with over 5 million articles is over 60 times larger than the next largest English language encyclopedia (Giles, 2018). While the architecture discipline has been relatively slow to adopt collective creation projects, the profession is now starting to change the way practice is organized networked and exchanged and we see colleges like AA, Columbia, Cornell, RMIT, MIT and SCI-Arc starting to adopt this modern methodology in their teaching (Hight 2006). Wikipedia, as defined by its goals of creating an encyclopedia of the sum of all human knowledge that is freely accessible by all, prompts this researcher to examine what is the architectural equivalent of the same and can it help accelerate the spread of sustainable design.

Aniket Kittur, a Carnegie Mellon university researcher found in a study related to collective intelligence that adding participants to a problem does not always make for a better solution, but it is rather the design of the framework that governs participation that ensures a growth of quality solutions (Kittur et al. 2009). This is best typified in architecture in the WikiHouse project, a collective, collaborative tiny house design project. The WikiHouse is perhaps the largest modern collaborative self-build design process in recent times. The project has over 500 members on Slack, an online collaborative forum, a portion of whom are contributors working on the Wikihouse roadmap of parametric design solutions. While there are many design programs written by the contributors, WikiHouse foundation only releases them after extensive testing of actual applications. Inclusion of environmental data and site information is one of the planned features on the WikiHouse future roadmap of parametrically adjusting features of the design, along with lighting, water, envelope design etc.

1.2. Big Data

Terrain data of most regions of the world is easily accessible at 30 or 10 meter resolution, while most of the United States is already, or will be in by 2018 available at a 1M resolution (NED 2018). The U.S. Climate Reference Network (USCRN) has over 140 climate stations spread across the United States that log accurate temperature information and the NEXRAD has 159 Doppler radars measuring precipitating and atmospheric data. The EPA's DRASTIC water vulnerability survey maps out at-risk locations across the United States that may be susceptible to ground-water pollution and contamination. Increasing amounts of LIDAR data across the world render highly accurate 3D point cloud models of tree canopies, land cover etc. Change analysis on these layers of data reveal patterns of growth and decay of many observable attributes. All this data is crucial to planned sustainable development, the key lies in the management, dissemination and reading of the data in systems so interdisciplinary functions of development can cohesively utilize the information and have the design fluently respond to said data. Computer coding is becoming more mainstream in the BIM industry allowing more ease with the digital connection between GIS packages, used by planners and landscape architects with those CAD and BIM packages.

1.3. Parametric Modeling and Digital Fabrication

Modern CAD and BIM software used by architects and engineers, such as Grasshopper a parametric design plugin to Rhinoceros, have made data processing tools affordable and accessible to a large market. Evolutionary design computation algorithms can take data such as solar exposure and optimize the form of a roof to output a structure that reduces solar gain in hot climates or increase exposure in cold climates. Similar computation can be applied to conduct surface analysis of land topography to very precisely predict water flow directions etc.

Digital fabrication is the most disruptive advancement in the manufacturing world since the industrial revolution, Computer numeric controlled systems of additive and subtractive fabrication are now becoming smaller, cheaper, faster and therefore more accessible. The ability to mass-produce irregular building components with the same facility as standardized parts introduced the notion of mass customization into building design and production. It is just as easy and cost-effective for a CNC milling machine to produce 1000 unique objects as to produce 1000 identical ones. As Catherine Slessor observed, “The notion that uniqueness is now as economic and easy to achieve as repetition, challenges the simplifying assumptions of Modernism and suggests the potential of a new, post-industrial paradigm based on the enhanced, creative capabilities of electronics rather than mechanics.” (Slessor 1997, 118-125). This means that for the first time we can now make the shift from mass production to mass customization to achieve site and environment specific optimized forms in architecture, which are built affordably with factory production quality specifications.

Architect Rachel Armstrong talks of Black Sky Thinking, an approach to design taking a speculative leap into the
future by observing current trends in technologies as a method to create frameworks of design that begin immediate engagement with innovative interdisciplinary technologies for design and development for the coming years (Armstrong 2017). Collective design, Big Data, Parametric modeling and digital fabrication are the resources of our times. Can we begin to forge connections between these new resources to help redefine the design approach to include optimized pragmatic solutions to environmental data? What this means to architecture is profound, we potentially have the ability to have our built environment develop in symbiosis with the natural world rather than against it. The editing and ethics of this data is paramount; what we want our architecture to respond to, and how the data is processed defines the form and function of our architecture and ultimately the longevity of sustained human life on this planet.

2.1. METHODOLOGY

Depending on the location of a site, there are various sources available online for many different kinds of geographical and environmental data. For most of the United States, United States Geological Survey is the primary resource for aerial imagery, digital elevation maps radar & land use land cover maps.[2] The process explored ways to translate the data available from various sources into drawings or forms that were readable by CAD softwares in order to run the custom written scripts or programs. In most cases the data is available in TIFF image format i.e. an image which contains metadata with geographical information contained in the pixels of the image pertaining to the location displayed on the image. These images can be read by GIS software that can further translate the images in DXF or similar drawing formats that can be read by design and architecture software. In the case of this research QGIS[3] was used as the GIS software and Rhinoceros was the design software, selected for its ability to run Grasshopper[4] a python based scripting software. Various custom scripts were developed that responded to the data to explore the possibilities of optimizing design for sustainability. The scripts developed are for site level intervention and for build level intervention[5](Fig. 1). As a demonstration of this framework of design, the paper will apply techniques learnt in this exploration to the design of an assisted living community of tiny homes on a 6 acre site in McMinnville, Oregon, a live project scheduled to be built in 2018. The site is currently predominantly untampered from its natural topography and eco systems, with only one permanent structure built, which gives this research the opportunity to examine best practices in approaching a natural site with minimal environmental impact.

The parametric nature of the programs developed in this project are versatile and customizable enough to be applied to any site or project by changing the input parameters of the program such as geographic location, site topography etc. and therefore can be applied as system of urban growth as cities expand to accommodate the demand for housing. The research will show that there is great potential in this system of data driven computational architectural design to achieve optimized sustainable design that is affordable, accessible and easy to fabricate. Since a lot of the tools used are open source and do not require special skills to run, the programs can potentially be adopted at the consumer level thus widening the influence of sustainable design solutions. While the most essential and basic elements of this thesis are achievable within technologies that are accessible today, the format of the thesis leaves room for modifications to the tools in lieu of future innovations in design and fabrication and the ever growing collection of data.

In approaching the project, the first goal was to develop a deep understanding of the watershed of the area and develop the site in response to it, so a site hydrology analysis script was developed. Since the client also wants to grow food on the land to support the homes on the site, the next consideration was to determine the areas on the land that are most suited for cultivation based on the solar exposure available in the dense forest site via a solar radiation analysis script. The build optimization is designed for structures that are based on the open source project WikiHouse that is a fully CNC manufacturable structure; new data driven design modifications were applied to the existing model that optimized the structure to respond to climate and environmental conditions. A surface optimization script modified the form based on solar gain requirements, and a foundation design script was written to design the footing of the structure to best suit the topography of the structure location. Further details of these four examples from the research follow.

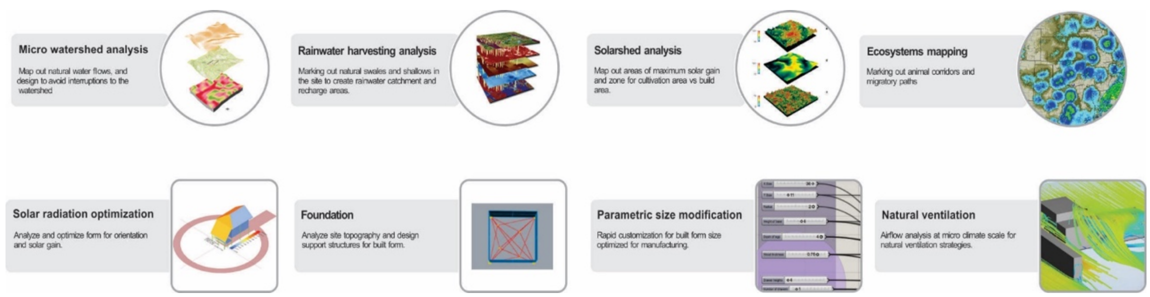

Figure 1: Overview of researcher's adaptations to existing WikiHouse.

2.2. Site Hydrology Analysis

One of the first elements of the ecosystem that gets altered when construction begins on a site is the watershed of the area. This is of significant importance when considering the ecological footprint of construction on the site and to attain or maintain the water quality standards in order to protect the flora and fauna that make up the carefully balanced ecosystem.

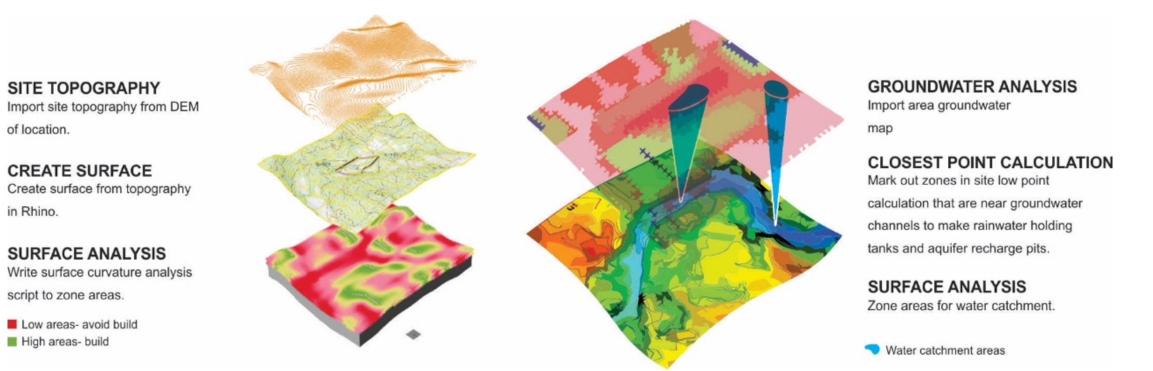

Figure 2: Layers of site hydrology and groundwater analysis.

A carefully managed watershed can maintain the physical, biological and chemical components that the local ecosystem has come to depend on (EPA 2018). In the absence of this understanding of the watershed, increased runoff from the site due to the addition of impervious surfaces can drastically alter the hydrology of the area. A micro-watershed analysis program was created as a part of this research to run a flow analysis in order to zone the site in such a way that the development does not interrupt the natural watershed of the area. This program workflow goes through two distinct software platforms, one is a GIS software that converts a

DEM image of the site location to a vector contour file, that contour data is then imported into a 3D modeling software and a triangulated surface is created from the contour data. Finally that surface is read by a grasshopper code that performs a surface curvature analysis and renders vector directions of the curvature from a grid of points on the surface. The vectors are assigned a color based on the vector attribute this renders a surface composed of green points to mark the high points of the site and red points that mark the low points.

The first step was to do a context water shed analysis to determine the position of the site in the watershed. A visualization strategy was applied to the program to render blue lines along the vector directions to simulate channels on the site that would form streams of water. This program was run first on the surrounding area of the site over a 1sq Km area. A second analysis was run on just the site, a 6 acre area. The site analysis provided zoning for where to build on the site and also areas that were most low lying on the site. This data, along with a groundwater map can be used to find areas to create rainwater catchment ponds, aquifer recharge wells, etc. (Fig. 2).

2.3. Site Radiation Analysis

The areas on the site that receive maximum sunlight exposure needed to be earmarked for cultivation, these areas will not be built upon in an effort to optimize the crop yield area of the site. LIDAR data was pulled for this analysis to create a triangulated 3D model of the site that was then imported to grasshopper to run solar exposure analysis. LIDAR or Light Detection and Ranging is a technique of remote sensing that uses pulses of lasers pointed at the surface of land usually from an airplane, the system measures the returning reflections of the laser to access the form of the land and generate a 3D point cloud of information.

LIDAR data for the site in Oregon was pulled from USGS data portal and triangulated into a 3d mesh using QGIS-an open source GIS software. The resulting 3D model contained highly detailed information about the site including the tree canopy heights-a crucial factor for establishing the amount of solar radiation available on the ground for cultivation purposes. Initial assessments made on the site using manual methods were time consuming and tedious, and provided little accuracy. Using the 3D model of the site, a program to run solar radiation analysis was written using Ladybug[6] that is a Grasshopper plugin. This analysis is usually run on building models to assess areas of heat gain based on geometry, orientation, and location of a structure. In this case a similar analysis was run on the entire site to render a heat map image of solar exposure on the site. The areas of maximum exposure were earmarked for cultivation and the remaining land was considered as sites for building structures (Fig. 3).

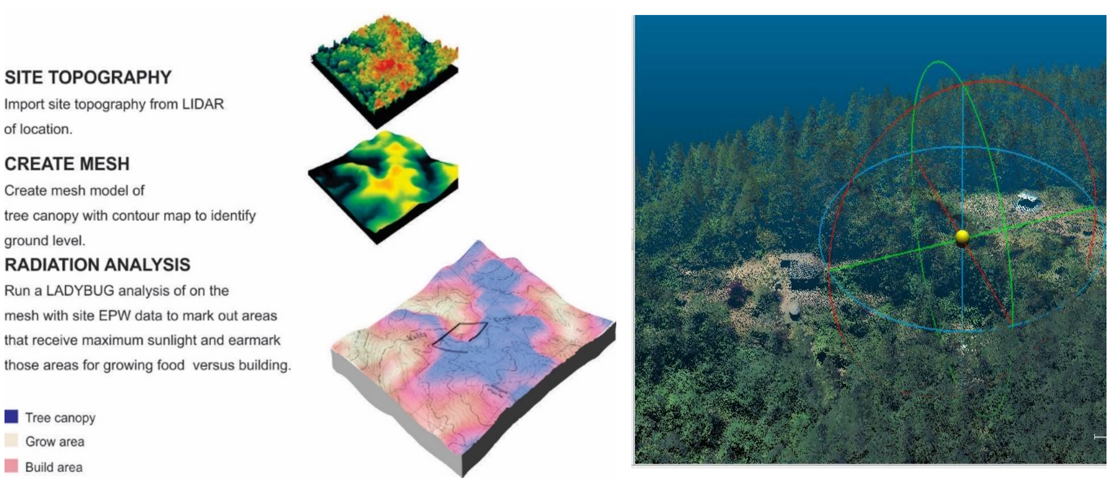

Figure 3: Solar radiation analysis process and visualization of heat map display and LIDAR point cloud image.

2.4. Structure Surface Optimization

As it stands the WikiHouse project has launched a Structure module; a parametric code that can be used to generate a custom sized skeleton structure framework and a Fit Out module, currently only a door design that can be CNC manufactured, but contributors are also working on programs for interior furnishings such as cabinets , etc. While these are the only two modules currently launched after intensive testing, the Wikihouse design framework also plans for various other levels of intervention: Envelope, Lighting, Water, Power, Data , etc. This portion of the research will be contributing to the Data modules, by creating programs for the structure to be optimized for climatic conditions to provide efficient passive human thermal comfort.

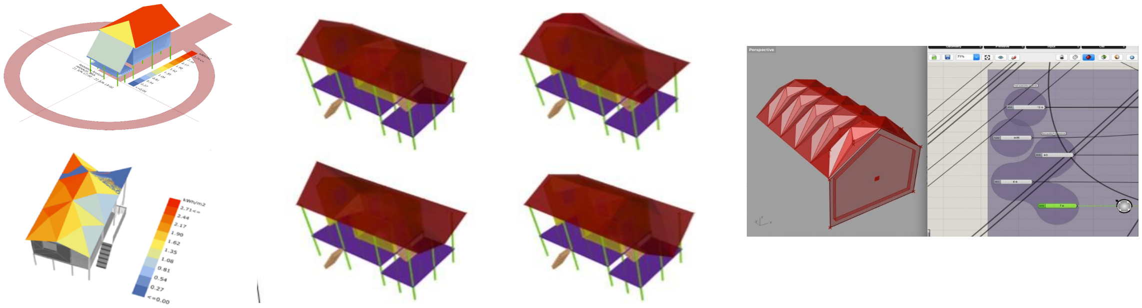

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Figure 4: Models showing roof solar radiation analysis and final optimized output

A program was written in Galapagos[7], an evolutionary computation module of Grasshopper, coupled with Ladybug, an environmental data reader in Grasshopper that inputs location weather data in the form of an EPW file that is a collection of about 30 years of temperature, humidity and rainfall data collected by weather stations. The program is given a set of parameters in the design of the structure that are decided to be flexible in their dimensions and the program runs through every possible permutation and combination of those parameters measuring the solar exposure in each and outputs the most optimal form based on the criteria specified, either to maximize or minimize solar gain. A script was written by the author for an academic project examining vernacular housing in Manaus, Brazil, where excessive solar heat gain via the roof was discovered in the analysis. The script was executed to produce a form that received minimum solar gain while maintaining the basic form and orientation of the structure. In the case on this project the requirement was to maximize solar gain by increasing the exposed surface on the roof. This exposed surface can also be used to achieve maximum area for roof top collectors for heating water, photovoltaic panels for power or glazed roof systems to introduce sunlight into the structure.

A similar program can be produced for the exterior walls with the flexible parameter being the fenestration sizes, measuring the solar gain inside the structure

2.3. Structure Foundation Design

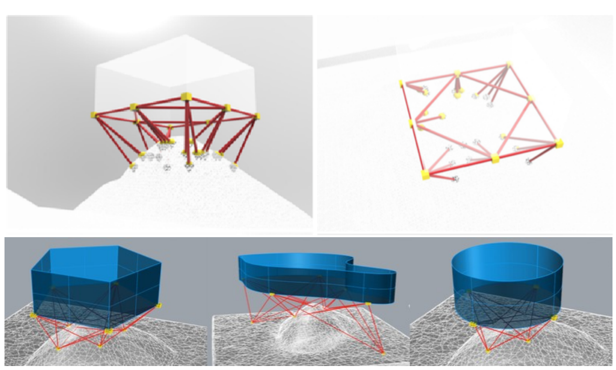

Figure 5: Renderings of conceptual foundation solutions working on a variety of topographies.

The Wikihouse model is a standard pier and beam floor that can be installed onto most foundation systems, for the purposes of this site we are recommending a raised floor system on stilts that connect to a diamond pier foundation block. By raising the floor of the house, we are further ensuring that the built structures have the minimum possible impact on the land and watershed. The stilts are parametrically calculated according to the input terrain data. A Grasshopper code written analyses the terrain mesh according to the location of the structure on the site and calculates the support design to use minimal material (Fig 5). The house base footprint is input into the algorithm and a code is written to place the base curve at a certain factor of height above the highest point of the terrain, cuboid support blocks are added to the base and then supports are rendered by discovering the closest points on the terrain from the support blocks. A foundation cone is added to the support pillars that depicts a diamond pier foundation block. Further refinement of the solution is warranted to generate a system that is structurally sound but this program serves as a demonstration of the concept and as a method of quickly visualizing terrain responsive systems.

3.0 FINDINGS

The entire framework of this research has created endless possibilities of nodes within architectural design for inputs of environmental data for the pursuit of sustainable development. Some of the scripts and programs written can function very well as stand-alone components of any project design and have implications to industries beyond architecture such as agriculture, urban planning and land use and water management projects. While the scripts worked for this project for the most part, the user interface is still too complex and intimidating to become a widely accepted norm in a design practice, the learning curve is steep but since the scripts are designed to be universally applicable, they may be worth the extra upfront time. The programs explored in this research may work for the specific outcomes defined for the research and may not be relevant for others, but the important takeaway is ease of interpolating GIS data with BIM softwares. Armed with this tool, the solutions as well as the problems themselves can be better defined and explored. While most of the data and software used in this research are open-source, there are other software programs with more advanced user interface design that are easier to navigate, but the prohibitive cost of those makes the scope of use limited and ultimately compromises the notion of widespread sustainable solutions. Additionally not all continents in the world have as comprehensive a collection and/or access to geographic information systems data.

Specific findings in the research pertaining to the site demand further investigations and testing, the hydrology analysis needs to be corroborated with experts in watershed survey fields to become an actionable solution; the roof optimization in the cold climate of Oregon may benefit from introduction of glazed roof sections to increase solar gain, additionally the form optimization may be more effective on the entire envelope of the structure and not just the roof; the footing design needs further refinement to make it structurally stable.

CONCLUSION

The impact of GIS data especially with its ease of access is an essential tool for intelligent sustainable development to address the climate challenges of today and the future; having our built environment develop in symbiosis with the natural world rather than against it is an attainable and essential program of development in the coming years. What can we achieve as goals towards sustainable development if we connect the vast amounts of environmental data we have-to urban design, city planning and down to the scale of individual project site interventions. Systems such as these have more impact when adopted by an entire neighborhood or community, the implementation of such knowledge on individual projects is only a stepping stone in this process.

As innovations in manufacturing technologies catch up to adaptive and changing forms in architecture, we may soon be able to build structures that are constantly reading geographic data, measuring climate health and adapting to best suit the ecosystems. While that technology may be in the future, we should begin to create a framework for GIS and other data inputs in architectural decisions.

While the backend processing of these systems, employed in this research are highly complex for the average home builder to invest in understanding, the hope is that with time and better user interface design- these programs will become highly intuitive and plug-and-play i.e. users can simply plug in their location data and output site specific solutions that are ready to implement. This would require a lot more research and development in the years to come, but until then these systems serve as a tool to support human design intuition and knowledge and vastly increase reach by offering faster actionable environmental data to work with. What this means for the profession of architecture is daunting in that we will see rapid shifts in roles and methodologies in the coming years, but like most modern vocations, the discipline of architecture will also respond and adapt to this brave new world and form what we will call the architecture of the Anthropocene.

ACKNOWLEDGEMENTS

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ENDNOTES

[1] Sustainable Development: Defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987), sustainable development has emerged as the guiding principle for long-term global development.

[2] USGS website source for GIS data sets, http://www.earthexplorer.usgs.gov

[3] QGIS is a free and open-source, cross platform, Geographic Information System (GIS) application that supports viewing, editing and analysis of geospatial data, https://qgis.org/

[4] Grasshopper 3D is a visual programming language developed by David Rutten that runs within Rhinoceros, by Robert McNeel & Associates, www.grasshopper3d.com

[5] All programs and scripts described in this paper have been developed for this research unless otherwise mentioned, with the help and guidance of University of Arizona faculty and the community of software users worldwide

[6] Ladybug is a Grasshopper plug-in that allows you to import and analyze standard weather data, http://www.ladybug.tools

[7] Galapagos is an evolutionary solver component of Grasshopper, http://grasshopper3d.com/group/Galapagos