PASSIVE ARCHITECTURE TOOL FOR EXPLORATORY DESIGN: CASE OF QATAR

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[PASSIVE ARCHITECTURE TOOL FOR EXPLORATORY DESIGN: Case of Qatar]

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[ABSTRACT]

By the middle of the twentieth century, the growing global demand for fossil fuels flooded the Gulf States with wealth that led to an unprecedented scale of city building. Today, Qatar is one of the highest consumers of energy per capita, with over seventy percent of energy in the residential sector depleted by air conditioning. In raising a metropolis from the sand, reliance on mechanical systems led to the largely unanimous abandonment of traditional building techniques that evolved from the hyper-arid environment to ameliorate harsh thermal conditions. Faced with a growing energy crisis, design professionals in Qatar have the opportunity to reduce demand and to maximize the potential of building and site by incorporating low-energy passive solar strategies into architectural designs.

This thesis recognizes the limitations of existing tools to assist with performance-based decision making during the early stages of the design process and proposes a new conceptual framework to explore architectural design and climate-sensitive strategies as drivers of the conceptual design with simultaneous feedback on cost-benefit implications. The thesis identifies single family residences as a key sector for future development and presents an interactive digital interface for generating site-specific design solutions and evaluating passive cooling strategies against selected performance indicators. Seeking to clarify the relationship between cost, energy, and design, the interface integrates existing tools in a gaming engine, Unity3D, to synthesize a component-based building system with analysis. The application requires little technical knowledge to operate and understand, allowing for quick experimentation and feedback. The simulation offers indicative estimates of embodied and operating energy alongside capital and operating costs while simultaneously allowing the user to assume an immersive first person perspective to experience the spaces. The tool is geared towards generating a process of iterative sketching and evaluation at the conceptual design phase in a simplified interface that allows for the flexibility of geometric expression while minimizing the level of complexity required for user input.

Embracing a belief in technology as a vehicle of social and environmental change, this thesis offers early insight into the efficiency of passive strategies and their economic implications throughout the building lifecycle. The result is greater transparency of the dependencies and compromises between pivotal variables for a variety of stakeholders. By allowing the architect freedom of form with low time investment, such an instrument offers an enhanced preliminary design methodology, promoting continuous negotiation between different configurations, and supporting divergent thinking through models. User testing and feedback demonstrates the potential of the tool to encourage energy-conscious decisions at the start of the design process, redefine the existing workflow, and engage users in a critical dialogue towards a culture of passive design.

Thesis Supervisor: James Wescoat
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[CHAPTER 1 : ENERGY SAVING IN QATAR]

Climate change has brought energy to the forefront of concerns across the globe. Qatar, a small desert state in the Middle East, is in need of reform to derail the growing energy crisis. While there has been much focus on replacing fossil fuels with renewable energy sources, demand management is also necessary for carbon abatement. This thesis proposes a digital tool that aims to facilitate the implementation of passive cooling strategies to alleviate the dependency on the air conditioning of indoor spaces. Passive strategies are low energy solutions that exploit building and mass, shown to reduce annual energy consumption of a residential building in similar conditions by over 23%[1]. Existing tools have been unable to transcend beyond automation of drafting processes; incapable of offering design freedom with low resource investment, the result is that energy analysis for architectural design is too often offset to a later stage where the majority of design is already determined. The Passive Architecture Tool for Exploratory Design (PATED) aims to support informed decision making during the early stages of the project by supporting design experimentation and exploration within the simulated contextual conditions of a particular site. The interface offers real-time feedback on the implications of passive strategies for approximated energy and cost performance criteria while minimizing complexity and user inputs. In redefining the design methodology, the thesis calls for a shift in design culture whereby energy efficiency becomes a driving force of conceptual design.

Curbing excessive consumption patterns is not an exclusive challenge to Qatar. Internationally, improving the building stock is one of the most economical ways of reducing demand. This chapter discusses the growing global and local dependency on energy as well as possible approaches to energy saving for this context.

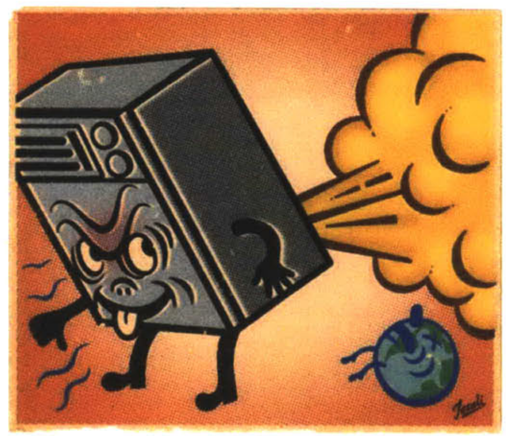


Figure 1: Harmful effects of air conditioning
Source: G Taxali, 2015

[1.1 AN ENERGY CONSUMPTION PROBLEM]

[GLOBAL ENERGY PROBLEM]

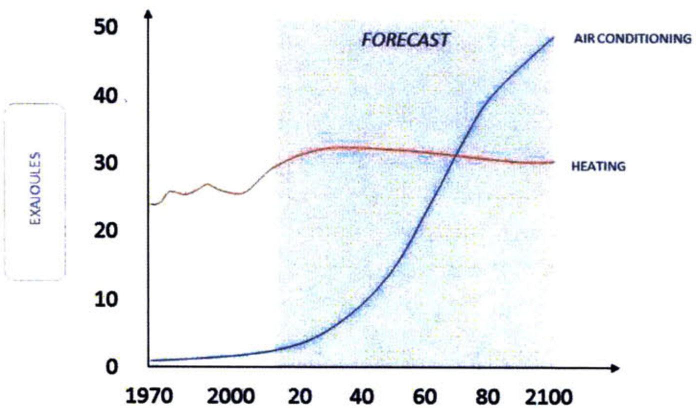


Figure 2: World Energy Demand

Source: PBL Netherlands Environmental Agency, The Economist, "No Sweat" January 5th, 2013

As global temperatures continue to rise, along with incomes, shifting smaller families into larger homes. The continent of Africa, home to a billion people, consumes less for all purposes, than the US alone consumes on electricity for cooling[2]. When considering that refrigerant leaks and energy use in cooling accounts for "around 10% of global CO_2 emissions. Already. [3]", demand potential from developing nations is foreboding. The number of urban Chinese households with an air conditioner jumped from less than 1 percent in 1990 to 62 percent in 2003[4]. Figure 2 shows projections that global demand for air conditioning is only expected to rise exponentially in the coming decades, by ten times by 2050 and even 40 fold over by the end of the century. The forecast for 2100 worldwide energy demand for air-conditioning factors an increase of 72 percent as a consequence of climate change alone.

[QATAR'S NATIONAL DEVELOPMENT]

Until the middle of the 20th century the Qatari peninsula was only sparsely inhabited by Bedouin tribes settled along the coast, primarily relying on pearl fishing for trade. It wasn't until 1973 that oil production and revenues increased dramatically, moving Qatar out of the ranks of the world's poorest countries and vaulting it to the other end of the spectrum. New hydrocarbon wealth combined with artificially cooled environments permitted an unprecedented scale of city development. Though it was not without cost. Today, Qatar is one of the highest consumers of energy per capita, and around 80% of energy in buildings is expended by air conditioning, the highest fraction of any country in the world[5]. Qatar has been classified as one of the least energy efficient nations in the world. WWF's Living Planet Report[6] identified Qatar as having the highest ecological footprint globally in recent years, a fate shared with other GCC nations like Kuwait and UAE.

[APPROACHES TO THE ENERGY PROBLEM]

Responses to climate change can fall under one of two categories that should ideally be pursued simultaneously: shifting onto renewable sources of energy and the reduction in the demand for energy. In 2005, in recognition of their responsibility to contribute to critical global targets, Qatar ratified the Kyoto Protocol and submitted an initial Communication to the UNFCCC in 2011. This Communication, addressing climate change and sustainability, was absorbed into the Qatar's National Vision 2030 as a central tenet. Within them, mitigation measures are described within a "national plan for energy efficiency, optimization and resource utilization[7]." Domestically, Qatar has an initial target of producing 2% of the country's total energy from renewable sources by 2020 and 20% by 2024. Their approach has been to initiate an initial 200 MW-phase of PV projects to supply desalination plants, along with dedicating resources to research into clean energy[8]. One such enterprise was funded $750 million from GCC nations, for research into technological solutions, notably carbon capture and storage[9]. Early in 2016, the Qatari national water and electricity utilities Company, Kahramaa, and Qatar Petroleum entered into an agreement to establish a $500million joint venture company with the purpose of investing in renewable energy projects[10]. These are laudable efforts, however, during the period required for eventual shift onto renewable sources of energy, there are many ways in which demand intensity could diminish.

[1.2 COMPLEXITIES OF ENERGY SAVING]

Accelerated growth in a harsh arid climate with lack of natural resources aside from hydrocarbons has meant that reducing energy demand in Qatar is ridden with complexities. Between 2000 and 2010, Qatar's electricity consumption more than doubled from approximately 8.0 billion kilowatt hours to 20.5 billion kilowatt-hours[11]. With reference to Figure 3, growth has continued, and to meet rising electricity demand, Qatar continues to invest heavily in its generating capacity. Qatar realized plans to boost generating capacity by more than 70% of the 2012 level to 15 GW in 2015[12]. High levels of consumption combined with robust population and economic growth will see energy demand continue to increase and greater domestic

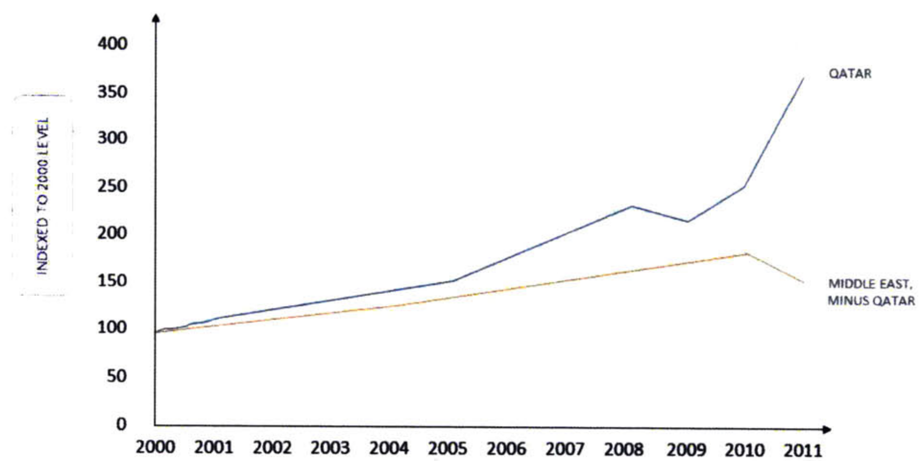


Figure 3: Qatar & GCC Electricity Generation Growth 2000-2011

Source: US Energy Information Association, 2012 consumption of energy will mean that less is available for export. Especially considering the current depression in oil prices, this could severely affect limited sources of national revenues.

[FLARING]

67% of Qatar's carbon dioxide emissions is due to fuel combusted during energy production, with 37% from basic oil and gas production and flaring responsible for 12% of emissions[13]. Qatar has been criticized for high levels of flaring that could be tackled through existing technology and policy reform, however, low domestic prices could mean that flaring is the most economical option[14]. Additionally, these wasteful practices have also been linked to detrimental air quality and health risks[15], noting that the Qatari population already suffers disproportionately from asthma[16]. Qatar has committed itself to achieving zero flaring from all of its oil and gas activities and so far the flaring reduction program has produced significant results up to 80%. Still, eliminating flaring represents Qatar's single largest energy-saving measure.[17]

[DESALINATION]

Endowed with huge reserves of natural gas but scarce fresh water, energy intensive desalination processes dominate as much as 40% of total gas use[18]. Conservation of water should, therefore, take priority since it equates directly to energy savings. In reality, Qatar ranks as one of the highest consumers of water per capita, estimated at 675 liters per day, four times to ten times more than many others European countries[19]. Growth of population, industry and agriculture has meant demand for water is rising at a rate of 12% annually, with further desertification and water scarcity likely in the future." [20] Water security remains fragile with a mere 48-hour emergency supply, though a plan has been initiated for a US2.7 billion scheme for five mega reservoirs to increase capacity to 7-day water supply by 2036.[21]

[CONSTRUCTION & GROWTH]

The high rate of construction temporarily distorts consumption patterns[22]. Around one-quarter of Qatar's GDP had been devoted to infrastructure in the past five years[23]. At the height of the construction boom, energy consumption grew 56% between 2001 and 2006 while an increase in population during this period was over 10% annually[24]. 2014 saw an unexpected 12% increase in its maximum electrical load in a period where the population grew by around 11%[25]. Rising demand can increase the risk of power outages, particularly in the summer months as residents rely heavily on air conditioning to seek refuge from the harsh days. The GCC is expected to invest $100 billion for the generation, transmission and distribution of 100,000MW of additional power capacity over the next 10 years, with 70% of the power demand growth due to growing air conditioning requirements[26]. Meanwhile the high rate of development has meant significant demand for another environmentally degrading resource with high embodied energy: production of Ordinary Portland Cement is responsible for total roughly 6% of all man-made carbon emission, releases on average a similar amount of CO_2 into the atmosphere, or in total roughly 6% of all man-made carbon emissions[27]. Qatar is notable for having 4.24 tonnes of cement consumption per capita, the highest in the world[28] and with major capital projects and infrastructure planned for the upcoming FIFA World Cup 2022, this is likely to remain high. Though we should be reminded that these high figures are measured in a period of extremely condensed and concentrated construction.

[ROLE OF BUILDINGS]

Figure 4 shows that Qatar's emissions from the domestic sector is nearly 80%. Residential buildings are the highest consumer, accounting for at least 33% of the nation's total GHG emissions[29], with around 80% of energy in buildings consumed by air conditioning[30]. The efficiency of power generation including extraction, preparation, transport, conversion and distribution may only be 20%[31]. Reducing energy demand, can be less expensive in many instances, than producing clean energy with advanced generation technology[32] while informed building design is one of the least expensive pieces of an overall strategy to minimize energy use and associated climate change[33]. Besides, efficient building design passes savings onto occupants with reduced utility bills that usually account for the highest occupant expense during operation. For example, it is reported that up to 40% annual energy can be saved small buildings through thermal envelope optimization in the similar climate of the Riyadh[34]. Another study of the RasGas building in Qatar concluded that in spite of subsidized energy and water tariffs, the realized economic savings justify green building initiatives.[35]

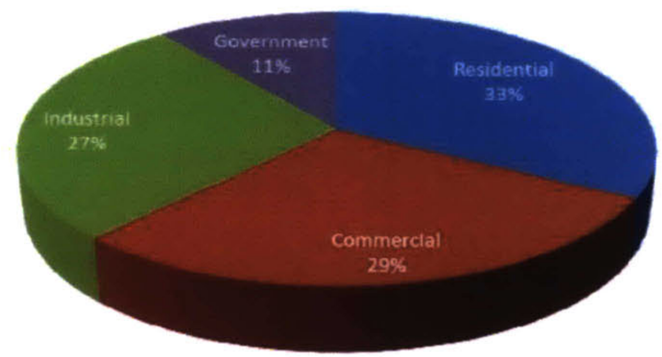


Figure 4: Classification of electricity consumption by sector in Qatar, in 2012

Source: A Gastli & Y Charabi, 2012

[1.3 RESEARCH METHODOLOGY]

Design professionals in Qatar are in a position to influence the energy demand of buildings through the implementation of passive solar cooling strategies. This thesis advocates for a forgotten ethos of implementing climate sensitive design strategies as drivers of the design process that can provide low energy solutions at a variety of scales to maximize the potential of building and site.

[THESIS OUTLINE]

To structure this research, I introduced in Chapter 1, the nature of the problem and some of the approaches and complexities for demand reduction in Qatar. Identifying buildings and air conditioning demand as the critical focus for improvement, Chapter 2 examines local demand management measures currently in place before investigating design practices, tools and processes available for energy analysis that can improve performance. The latter half delves into detail on the current local practices, tools and processes available for energy analysis in the early stages of the design process. Research on historical and contemporary precedents argue the benefit of embedding passive cooling into the design process and culture. Based on the deficiencies of existing tools on the market, Chapter 3 develops a new conceptual framework for a digital design tool that offers architectural freedom in an immersive environment with feedback on energy and cost criteria for design choices. This chapter details the resources, rationale and references guiding the original work and establishes a series of value propositions for a successful tool. Development of the front end and back end of the software will be presented in Chapter 4. The proposed tool integrates design and analysis in a video game development platform to bridge the gap between intelligence and usability. In Chapter 5, results from testing and evaluation of the prototype are presented as primary research. Potential users provide insight into existing design methods and tools while barriers to early energy analysis are investigated, followed by feedback on the proposed conceptual framework, identifying future areas of work. To conclude, Chapter 6, will summarize the successes and limitations of the prospective tool, before offering suggestions for further research, in addition to concluding remarks advocating for holistic demand management.

[CHAPTER 2: DEMAND REDUCTION IN THE QATARI CONTEXT]

Demand management of the built environment can be improved through different avenues, such as making changes to occupant behavior, materials, equipment efficiency, construction design, details and construction. This chapter will begin by outlining the different ways in which the Qatari market has approached curbing high energy demand from buildings. Compiling tools available to designers to assess the energy performance of their designs, the next section reviews existing software available to evaluate their role and limitations within the design process. Exploring the potential of passive architecture, historical and contemporary precedents are presented to argue that passive design can be valuable to reduce energy demand, as well as enhance national heritage.

[2.1 LOCAL DEMAND MANAGEMENT MEASURES]

[PRICING MECHANISMS]

Pricing mechanisms are a primary way in which governments regulate demand for energy, even going so far as to implanting carbon pricing policy and taxing structures[36]. Richer asserts that correcting market failure through heavy taxes, resulted in greater product efficiency and redistributed funds into social and environmental programs in many European countries[37]. In the Qatari case, as a fuel producing nation, energy prices are heavily subsidized. Nationals are exempt from paying for water and electrical utilities while overall prices are relatively low. With oil reaching record lows in the past year, diving below $30 a barrel, budgets signaled a need for a price adjustment, increasing the price of petrol increased by over 30%[38]. Taxing cars on engine size and fuel efficiency can help to decrease purchases of larger cars. Similarly, electricity and water costs rose for the first time in over a decade, with a usage tariff based pricing system that will more than doubled costs for some users, despite still being heavily subsidized[39]. Tariff based strategies and the high cost of energy has been shown to be a deterrent to wasteful use[40]. Without sufficient incentives or penalization to occupant behavior, Qatar relies on residents' social consciences. In recognition of the leniency of current pricing, fines and penalties have increased for wasteful practices such as leaving hoses running or external lights on during daytime hours of 7am to 4pm, by enacting legislation that makes wasting water and electricity punishable by fines of up to QR20,000, doubling the previous limit [41].

Figure 5: Tarsheed twitter post, October, 2015

[SOCIAL AWARENESS]

Having been shielded from the internalization of external costs, the consequence of social disassociation between the cost of resource production and use efficiency must be reversed. The government has been increasing efforts to stress the importance of conservation through public awareness campaigns that enlist social media, such as Tarsheed on Twitter, seen in Figure 5. Urging citizens that conservation is a religious, national and moral responsibility of every person, Prime Minister Sheikh Abdullah bin Nasser bin Khalifa Al Thani iterated "There is no alternative to preserving natural resources for us and for the coming generations."[42] The program sought to reduce the consumption of electricity by 20% and water by 35% between its launch in 2012 and 2017. By November 2015, Tarsheed reported success in reducing the per-capita electricity and water consumption by 14% and 17%, respectively, equating to savings of more than 800 million Qatari Riyals ($220 million)[43]. In a continued bid to keep reducing consumption, Kahramaa announced that all residents will be sent monthly water and electricity usage reports by text messages as well as advice on recommended targets for their building [44].

[EFFICIENCY STANDARDS & REGULATIONS]

Backing Tarsheed, the Ministry of Environment have announced a plan to phasing out the sale of conventional, power-hungry air conditioning units, with only energy efficient options offered on sale in local stores [45]. These new high-performance units can consume up to 30% less power. Alongside this initiative is the hope to ban the import of tungsten light bulbs in favor of energy-efficient LED alternatives, as well as introduce standards for other mechanical equipment such as refrigerators, freezers and washing machines[46]. Limiting the available supply in the country is an effective approach against cost sensitive consumers. Unwilling to allow the improved efficiency in air conditioning units to be hindered by improper building skin, Kahramaa have started to set standards on the thermal insulation of ceilings and walls for new constructions, to maintain indoor temperature and potentially reduce demand for cooling by up to 40%[47]. Similarly, in 2010 they mandated a maximum of 60% glazing of facades, double glazed at least 12mm and QSAS silver rating required for all new projects, in response to a growing number of glass towers with poor indoor environments[48]. Other equipment side solutions include the introduction of district cooling systems that can provide up to 50% of savings of electrical consumption through economies of scale, compared to traditional HVAC, though may also be more that 50% more water intensive.[49]

The "Electricity and Water Consumption Rationalization Law. No for Waste: 2009" authorized Kahramaa to "develop the technical specifications for thermal insulation and power saving measure in buildings, update the technical specifications for electrical and internal water installations and upgrade the audit methods to reduce power and water loss in premises with high consumption" amongst other initiatives[50]. For monitoring and reporting, Kahramaa intends to complete the initial rollout of the smart meter project across the city this year[51]. Smart meter or sensors disseminate real-time data on the energy or water consumption of a building to consumers so they can better understand their own energy use and help identify energy saving opportunities. A study based on existing trials showed that homeowners' electricity consumption reduced on average, by approximately 3-5%[52].

[BUILDING CODES]

The built environment has been no exception to ongoing efforts to improve energy efficiency. In 2009, Qatar launched the Qatar Sustainability Assessment System (QSAS) a green building certification system based rating systems such as LEED and BREEAM, incorporating it into the Green Building Code of the 2010 Qatar Construction Specifications[53]. QSAS is divided into eight sustainable categories and sets of criteria, each with a direct impact on environmental stress mitigation in the following areas: urban connectivity, site, energy, water, materials, indoor environment, cultural and economic value, management and operations.[54] Rating is mandatory for all public buildings and it has been proposed for residential and commercial compliance in the next few years.

LEED suffers from criticisms of being too complicated and costly, requiring an accredited QSAS Certified Green Professional to facilitate submittals of projects for assessment, making it too expensive for small projects and businesses. Also, by setting benchmarks instead of standards, the points-based format of the system means that costs may be added so that points may be collected through value-less features, and that measured performance of certified buildings haa no bearing on actual energy efficiency[55]. The QSAS system neglects the interpretation of essential local sustainability measurements in their assessment, and they further "fail to suit the local context culture issues, resources, priorities, practices and economic challenges.[56]"

Caution must be taken with buildings claiming efficiency under these certifications as they are susceptible to greenwashing; without having to prove energy efficiency, several comparisons[57] are revealing that there is a disconnect between projected and actual building performance, and there is "no scientific basis... for LEED-certification as an energy reduction strategy for its buildings.[58]" Gifford warns of the risk associated with a standard that is not predicated on measured performance of LEED buildings, consequently, "the best data available shows that on average, they use more energy than comparable buildings... The LEED system is not only ineffective, but is harmful to the environment... and to effective energy saving methods which are ignored in favor of the image of energy efficiency. LEED should be abandoned immediately, and be replaced with a system that is based on actual verifiable energy use measurements.[59]"

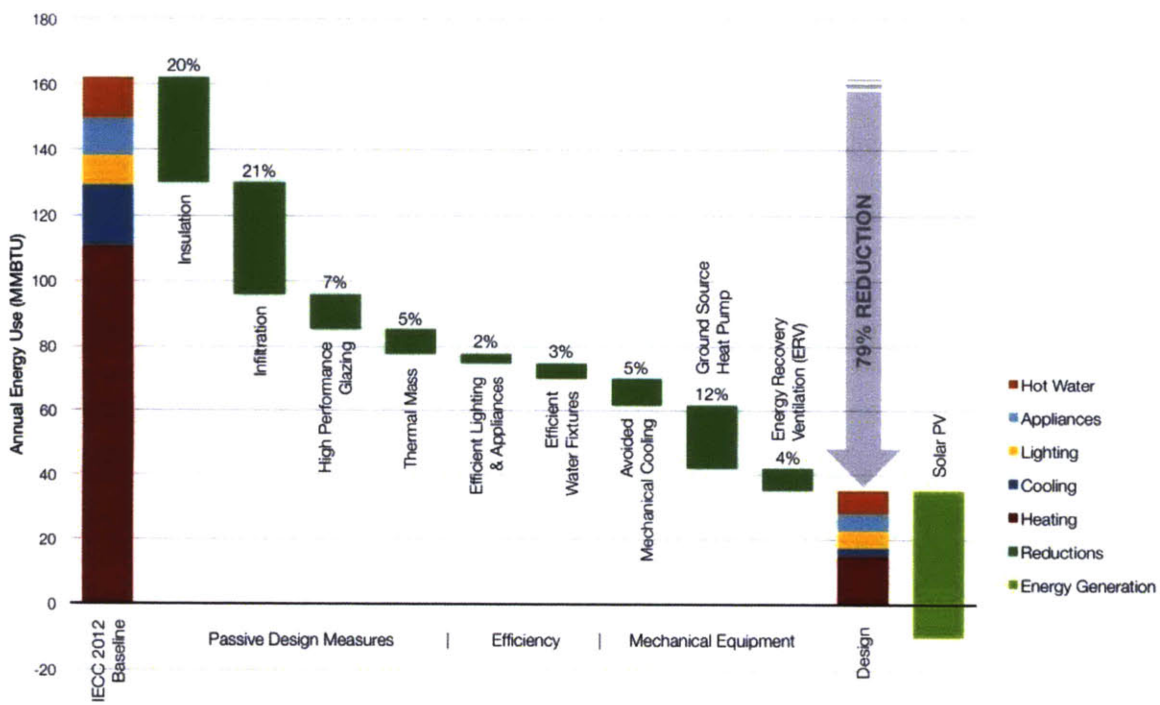


Figure 6: Path towards net zero: Energy reduction strategies and on site generation

Source: S Aruofor, 2015

[ARCHITECTURAL DESIGN]

Laws and regulations prescribing passive formal restrictions on architectural form such as insulation and glazing have been incremental, but perhaps are a response to that realization that wider application beyond rated buildings is necessary for meaningful impact. Figure 6 shows how a series of passive and active measures can drive down consumption in buildings. A passive building uses on-site sources of energy, relies on natural energy flows with a minimum of moving parts, integrates production, use and efficiency by the building's design and form.[60] In practice, architects are widely excluded from energy evaluations of their buildings. The result is that some of the most efficient energy reduction strategies are not even considered until a design has been developed, leaving only the more costly system upgrade[61]. Offsetting energy analysis to the detailed design stage means that by this point, many of the major design decisions that will impact the energy performance have already been made and can then only accommodate slight variations. Passive design embodies a design process that is integrated from the inception of a project. Energy efficient family houses provide residents a high quality of living comfort, thus thermal comfort, daylight and air quality[62].

Due to strict regulations against informal housing, leveraging approval of the building permit is an effective way to force developers to invest in user comfort and long term energy efficiency instead of maximizing profit. Expatriates have only recently been granted permission to own land or property in a select number of segregated, high income developments. As such, they dominate the rental market for apartments leaving only 5% as owner occupied; Nationals instead prefer to stay in villas where owner occupied properties account for 45% of the total.[63] The majority of residential housing is built by local developers on private land to generate rental income. Combined with a severe housing shortage, developers have therefore had little incentive to cater to the long term interests of transient renters, sacrificing thermal comfort and energy efficiency, and inducing higher operating costs to unsuspecting residents.

[2.2 DESIGN PRACTICES & TOOLS]

It should be stressed that the first opportunity to provide efficiency is in the architectural design. Passive design is embedded in the building envelope's formal and material choices, therefore it is imperative it be introduced early. By exploiting the natural resources of a new constructions micro location and with the appropriate building designs and orientation we define any consequential energy requirements and technological measures as necessary. Only after verification of the architect's optimal solution is the option to design different technological variants considered, to satisfy remaining energy requirements for zero-carbon solutions.

[2.2.1 CONCEPTUAL DESIGN METHODS]

Schon describes the conceptual tasks that any design professional faces, as the creative production of design solutions to solve a particular problem, to be then assessed for its merits.[64] Design problems have no explicitly specified target state, often no defined specified set of processes or operations that may be used to reach a solution, nor a natural end, allowing infinite refinement of a design solution, by discovering and altering new parameters. That is why there is no such thing as a "best solution"; there are only better ones. However, "wrong" solutions are useful too because they serve as lessons and guidelines. Design processes incorporate creativity, synthesis and problem solving. Termed 'Visual Thinking', or 'Reflection in action'[65] or 'Divergent Thinking[66]' "the tools facilitate a creative feedback loop between ourselves and the visual representations of our ideas, by externalizing our thoughts in the form of sketches[67]" He suggested that through sketching and experimenting, the designers are able to quickly and cheaply, create a virtual world in a drawing that "disclosed qualities and relations unimagined beforehand.[68]"

The text Reflection in Action[69] explores the role of the architect, the studio, and their method of practice, whereby thinking gives rise to experimenting. He explains that in the "unstable world of practice, where methods and theories developed in one context are unsuited to another, practitioners function as researchers, inventing the techniques and models appropriate to the situation at hand." Architects use drawings and models to test new understandings, explore new phenomena, and to asses or eliminate the alterations by which the practitioner tries to change things for the better". Through inquiry and experimentation, the process has the quality of a reflective "conversation with the situation"[70], that triggers a reframing of the problem or better understanding of constraints.

Heidegger divulges: by inquiry: "Every questioning is a seeking. Every seeking takes its direction beforehand from what is sought. Questioning is a knowing search for beings in their thatness and whatness. The knowing search can become an "investigation," as the revealing determination of what the question aims at."[71] Thus a tool tries to support the designer as he evaluates in a threefold way: "in terms of the desirability of their consequences judged in categories drawn from the normative design domains, in terms of their conformity to or violation of implication set up by earlier moves and in them of his appreciation of the new problems or potentials they have created. As the design evolves, possibilities and freedom of choice reduces shifting into an acceptance of the imperatives which follow decisions.[72]" It is important to note that the choice of tools are strategic and by no means "innocent": "Computer applications externalize in their graphical interface and in their internal logic a set of assumptions about how objects are constructed and space is represented. Software selection affects design outcome.[73]"

[2.2.2 COMPUATIONAL SUPPORT]

Pioneers of CAD, such as the Architecture Machine Group at MIT during the 1960s, conceived of greater visions of computer-human collaboration. Negroponte speculated on how CAD tools could perform as socio technical agents: active partners with superior intelligence that would partake in the design decisions. On the other hand, Friedman shifted the focus to his vision for architecture without architects, allowing non experts to make designs for their own needs to bear the risk of failure through rational and symbolic conversation between user and machine.

[REVIEW OF EXISTING SOFTWARE]

Building simulation programs can also be known as 'Design Tools' or 'Detailed Simulation Tools'. To assist with the conceptual design process, tools must be able to both provide the user with design freedom in a system that allows rapid prototyping of digital models. Meanwhile, it should offer intelligence by evaluating key variables of energy and cost performance of a design. Some existing tools with their respective plugins are compared to evaluate their scope and limitations. These fall under two categories: commonly used Building Information Modeling (BIM) software intended for detailed design and an emerging market of tools targeting conceptual design.

Figure 7: Comparison of existing design software

[DETAILED DESIGN TOOLS]

Available software on the market that are capable of performing these combined assessments are highly technical and often expensive, developed with a focus on task rather than the user. As a result, this exercise is either neglected or undertaken during the detailed design stage, at a point where there is much less flexibility for changes. Full cost-benefit analysis is restricted to high-level 3d modeling interfaces such as Rhino3D, DesignBuilder and Autodesk Revit that rely on external plugins to add the functionality of analysis. EnergyPlus for example is a validated building energy simulation program that was developed by the US Department of Energy for modeling building heating, cooling, lighting, ventilating, and other energy flows, able to capture many details but lacking in accessibility. Communication of ideas and interpretation of results also becomes a critical issue during interdisciplinary collaboration, where team members must be able to understand the implications of results. Information architecture and graphic presentation of data can play a significant role in representation, understanding and learning.

Ability to use these will be limited to trained individuals who will focus on analyzing a defined design option. The laborious setup of simulation models with high computation time and complex inputs, increases risk of error and miscalculation and hinders the use of such technology in early design phases.[74] These software share similar interfaces, containing a viewport to the 2D or 3D modeling environment, flanked by toolbars for users to define actions. Most software is simply not adequate to accommodate all tasks within its platform. The shift towards increasing specialization has hindered cross interdisciplinary integration of both knowledge and tools. Most will require the assistance of other software to complete analysis. For example, the new Passivhaus plugin to Sketchup still requires export of the data collected from the model into Excel, while the model itself requires ample time to develop, the disruption between design and analysis impedes a process of associating sources of comparison during quick, successive iterations. Conceptual brainstorming processes through a 'trial and testing' solution-oriented approach, do not work well with the software intended for producing construction documents.

[CONCEPTUAL DESIGN TOOLS]

Meanwhile, there is a multitude of conceptual modeling software being released that are singularly focused for a specific task, where the fault may lay in their lack multiple analytical features or are too limited in design freedom. Recently applications targeted to a mass audience such as homeowners have had to transcend the complicated interfaces of sophisticated tools using a small number of large icons to offer a user access to a catalog of predesigned components that can be used to develop designs and plans. While these are focused on usability, there has been few instances in which the tool provides feedback or intelligence.

Design through play has been gaining momentum, capitalizing on the potential of transforming educational opportunities into engaging learning environments. Several tools have developed out of this idea for different purposes such as daylighting, comfort & lighting[75]. Most relevantly, a study on the use of play to promote energy decision-making found that students understood and enjoyed the use of design simulation DesignAdvisor [76]. While the interface focuses on intelligence with minimal inputs and supports the comparison of proposals, it is limited in that you can only compare computer-generated forms. Rapiere, a similar tool for intelligent analysis early in the design, can accept a 3D Building Information Model (BIM) and attribute it with specification data to run simulations. Both of these have constrained their interfaces and systems, addressing the issue that the early design phase usually lacks sufficient information for these models, but both are not yet able to allow the designer to externalize complex proposals or discover unexpected solutions.

[LIMITATIONS]

CAD tools have stagnated for and researchers 20 years also were already bemoaning that "the integration of computers into the creative stages of the design process has not developed as quickly or effectively as was anticipated by the early pioneers of computer based architectural design." [77] While they undoubtedly transformed architectural production, efficient as "computerized versions of traditional drafting", they are not yet capable of supporting the cognitive processes of design, problem solving, nor solutions finding, beyond the mechanics of drawing.[78] With high client expectations and low fees, the conceptual design phase faces continual pressure of reduction, to facilitate progress towards primary deliverables and with them, the bulk of fees. Once fees are secured, the design team can invest to develop and refine a solution. Investment in design does not take place until later stage anchoring software to technical automation to try to capitalize on the detailed analysis and drawing production. However, as a result, these tools are not quite equipped for creative design and users lament "Poor tools make for a poor process, making conceptual design with these tools frustrating, inefficient and expensive.[79]"

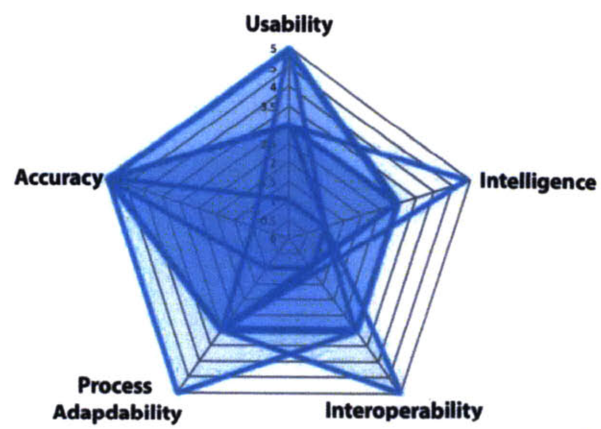


Figure 8: Results of Analysis of Design Tools
Source: Attia & de Herde, 2011

The comparative method is integral to conceptual design, whereby the architect proposes many alternatives in order to compare, select and reject. Unless there are two different proposals for comparison, the designer is unable to grasp the nature of the problem sufficiently, with the risk of a biased perspective: "Generating a variety of solutions is a means of problem analysis."[80] Improved decisions are contingent on the selection of a solution from a range, based on certain criteria.[81]

Ritter identifies three key failings in currently available tools: in that they do not provide Design Decision Support throughout the design; they are unable to support collaborative and interdisciplinary teamwork; and, they are highly complex and have a correspondingly steep learning curve, so can only be operated by experts[82]. To overcome these shortcomings would allow CAD tools to be useful agents in the creative processes of early design able to match the versatility of conventional paper. Attia and de Herde[83], in their assessment of 10 different 'Architect Friendly' Building Simulation Tools, as shown in Figure 8, found that overall there was a gap in the market for tools that exhibited both high intelligence and usability.

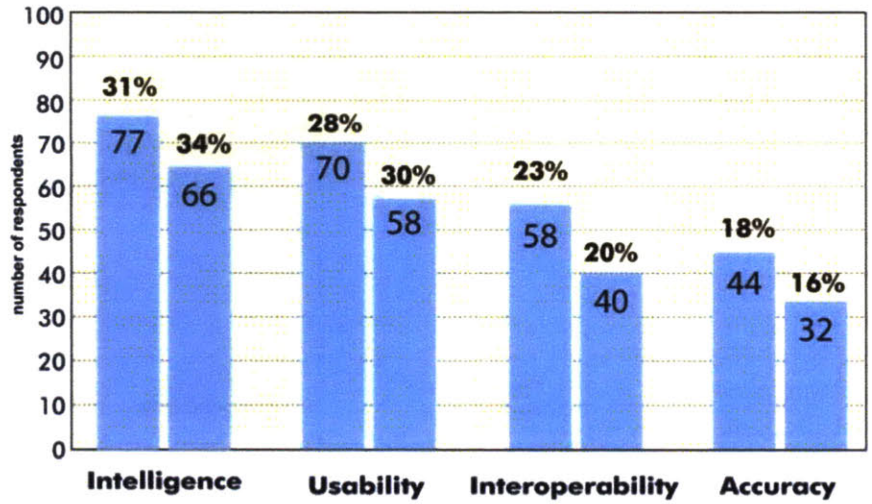


Figure 9 : Architects rank priority features of a simulation tool

Source: Attia & De Herde, 2011

[DESIRABILITY]

Examination of design tools in architectural context: "Tools must be flexible in their application, provide some form of direct cognitive feedback from gesture to brain, be able to accommodate vague input, and facilitate a step-by-step approach to problem solving"[84]. Thus, the challenge here is to simplify inputs and combine intelligence in an immersive way to experience space. Visual simulations such as walkthroughs and flybys are becoming more ubiquitous as a means of communicating the spatial proposal. One study has produced the conclusion that digital visual representations can be utilized to achieve a better understanding of the form because, compared to traditional freehand tools, the intensive visualization and immediate feedback in computer media assists the designer in spatializing their ideation.[85] Conceptual design needs to find the right balance between healthy productivity and a degree of freedom that will promote creativity and allow diversity. Also, it showed that users prefer to use a single tool rather than alternate for various tasks, to avoid loss of information during the transposition.[86]

CAD systems have always concentrated on the representation of form and the provision of tools for changing and assembling form. The rules used by artists and architects are often speculations: The drawing or model poses a question: Given this, what next? What happens if...? Figure 9 shows results of a study where architects ranked priority features for a simulation tool with the ability to integrate intelligent design knowledge base to assist with decision being the respondent's highest priority[87]. Friendliness of the user interface concerning usability and information management was next most important factor, in which existing tools are deficient for architects' working methods and needs, having a higher priority than accuracy. Users are interested in a tool integrated with performance analysis methodology that can seamlessly substitute design processes without substantial deviation from existing practices.[88] The user should experiment, iterate and evaluate a building's performance according to cost and energy indicators to inform decisions and support learning about dependencies of passive design. An essential characteristic of an architectural design tool is to allow the designer to traverse back and forth between options without interruption[89]. The current state of software is discussed: "Digital design tools have been challenging the ways architectural forms, in particular those generated by topological geometries, are conceptualized, explored and built. However, research in the former area has been focused onto its technical aspects without taking into account the ways environmental design can be integrated in the conceptual stages of architectural design."[90]

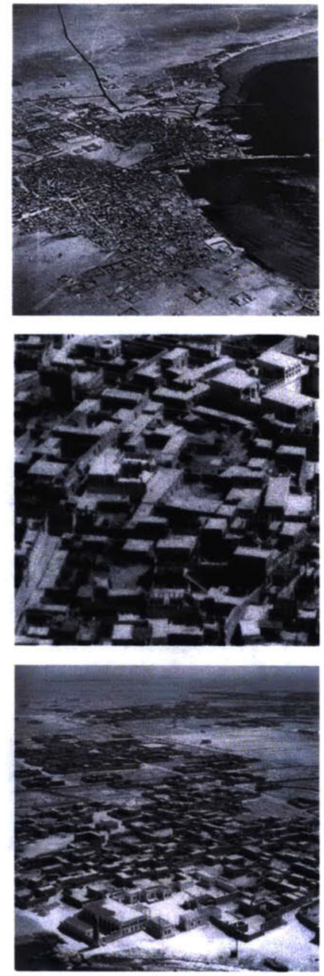


Figure 10: Aerial Photographs of old Doha 1950-1960

Source: catnaps.org

[2.3 DEMAND REDUCTION STRATEGIES: PASSIVE ARCHITECTURE]

[2.3.1 HISTORICAL PRECEDENTS]

The harsh climate has meant that residents of the region have always sought ways to keep the heat out of buildings and conserve resources. Vernacular buildings of the region exhibit this form of sustainability that uses passive cooling techniques such as wind towers, night cooling with shading and evaporative cooling.[91] Passive architecture responds to thermal flows in a site from various sources: solar radiation, external air, live occupancy, and sinks, sky, external air, wet surfaces. Passive strategies are more effective when implemented in the right environment, for example, where cooling is required, avoiding direct solar glare through shading, and using insulation, roof ponds or night ventilation could greatly improve the internal conditions of a space. A principal purpose of a building is to change the microclimate, and this had been refined for centuries prior to industrialization and mechanization. These strategies were developed through processes of experimentation and the experience of generations of builders and worked at every scale from the urban down to individual rooms.

The original urban fabric of Doha centered around the port was composed of dense and compact mud housing, mainly of the courtyard typology, exploiting the thermal mass of natural materials and shading from surrounding buildings. It was organized by "Feerjan" stretched parallel to the irregular indentation of the salt marshes and tidal flats along the Arabian Gulf shoreline with alleyways that penetrated the urban area lead to the harbor, the busiest part of the city.[92] "The housing stock was composed of a few hundred simple one floor dwellings huddled closely together along narrow, winding alleys." [93] Master masons were responsible for the design and execution of the house with a few workers. Researchers assume these workers originally hailed from Persia or other nearby regions with similar climatic conditions, who brought expertise in masonry construction and wind towers.

[2.3.3 CONTEMPORARY ARCHITECTURE IN QATAR]

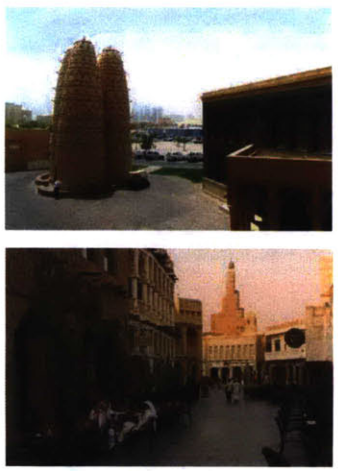


Figure 11: Katara Cultural Village (above) & Souq Waqif (below)

Sources:

http://thefreedomtraveller.com/2012/04/19/katara-cultural-village-doha-qatar/http://www.landscapeinstitute.org/news/modern-landscapes-of-doha-qatar

Passive and low energy solutions never disappeared, they just fell out of popularity. New typologies of building arose, namely the stand-alone villa and apartment buildings to accommodate changing social structures, lifestyles and the influx of expatriate families. Concerns over rising temperature increasing desertification globally, has instigated more rigorous analysis of best building strategies in hyper arid environments. While these have somewhat been relegated into marketing points for explicitly "sustainable" projects, there must be a societal shift that shares accountability to conserve resources and relatedly improve performance of the building stock at a mass scale, whereby it becomes the norm and not the exception. As we saw from Figure 2, residential consumption is the highest proportion and has been the least regulated thus far.

Globalization and the import of professionals and architectural ideas from external contexts has meant drastic change to the city. Since the commission of Llewelyn Davis for the first formal masterplan for Doha in the late 1960s that expanded and demolished the old city core, today, the skyline is a testament to the manifestation of this new global condition.[94] In response, a national project of heritage and cultural preservation has manifested in museum building and cultural commercial developments such as Souq Waqif and Katara Cultural Village, as shown in Figure 11, which ascribe to an Orientalist representation by employing the superficial imagery with surface and façade treatments, rather than reflect an understanding and reconciliation with the knowledge of the ways in which to adapt and inhabit the land. Upon reviewing design practices, three types of efforts towards image-making were identified in Qatar: utilizing symbolism in contemporary imaging, manifesting tradition and modernity discourse in search for image identity, addressing the global condition towards image-making.[95] This led to the flattening of the inhabited historical core in a process of gentrification that would reflect their desired projection for more attractive commercial and tourist destination. The result is catering to international perception through selective branding projects claiming authenticity, rather than conservation of building traditions and knowledge that has been accumulated over the centuries and disseminated generationally. Salama[96] cites that "the results have been mixed, resulting both in places that authentically incorporate a sense of place, as well as places that utilize inauthentic and shallow forms of 'theming' to evoke past histories and otherness."

[2.3.4 HERITAGE / CRITICAL REGIONALISM]

Described an architecture of resistance, this thesis advocates for critical regionalism for contemporary architecture, "that should neither be branded as internationalism nor as a folkloric or historical concept of region, but should be more responsive to regional distinctiveness and the possibilities of meaning available at that locality."[97] The imported International Style has been criticized for its inability to respond to both local climate and society.[98] This is not to suggest that there should not be adaptation to new technologies and a globalized climate, however, there should be greater effort to learn from and translate traditional strategies of the region into contemporaneous forms. The relationship between a design and the unique characteristics environment and climate, can be understood and interpreted, developing further the local identity and knowledge by contributing much more effectively to environmental, social and cultural preservation. "In order to assess the value of our heritage in architecture and to judge the changes that it has undergone, there is a need to analyze scientifically the various concepts of design. The role architecture and town planning play in the progress of civilization and culture must be grasped. While change is a condition of life, it is not ethically neutral. Change that is not for the better is change for the worse, and we must continually judge its direction. Architecture concerns not technology alone but man and technology, and planning concerns man, society, and technology."[99]

By the middle of the twentieth century, a number of prominent Arab architects in the Middle East focused on the issue of climate as a key constraint of the region. In 1945, Mohammed Saleh Makiya[100] completed his PhD dissertation at King's College Cambridge on "Architecture and the Mediterranean climate: studies on the effect of climatic conditions on architectural development in the Mediterranean region with special reference to the prospects of its practice in the 'Near East.'" Before returning to Iraq to establish a renowned regional practice. Another fellow Iraqi, Hisham Munir[101], presented his master's thesis in 1956 to the University of Southern California, titled 'Climate control and Architecture in Iraq', summarizing the nature of the problem in the opening statement "Of all the factors that impair the development of a nation, the most permanent is climate (1956)". Central to Egyptian Hassan Fathy's [102] text on Natural Energy & Vernacular Architecture was that "The climate of the locality and the buildings around it mold the building, so that, even though social, cultural and economic aspects are important, it owes much of its shape to these factors." He later goes on to criticize "international architecture" based on the use of high technology materials such as the reinforced concrete frame and the glass wall. He further asserts that despite freedom from nearly all material constraints, the architect today has "responsibilities to what surrounds the site, and, if he shirks this responsibility and does violence to the environment by building without reference to it, he is committing a crime against architecture and civilization." Despite some notable efforts to bring awareness to synergetic passive cooling techniques that emerged from the region as viable solutions to continue climate mitigation, there has yet to be significant implementation. Trying to understand why there has been such limited uptake, led me towards devising a framework for an accessible tool that could be congruous with a designer's methodology.

[CHAPTER 3: CONCEPTUAL FRAMEWORK]

"Architecture is monstrous in the way in which
each choice leads to the reduction of possibility.
It implies a regime of either / or decisions
often claustrophobic,
even for the architect."

- Rem Koolhaas, OMA[103]

The previous chapter concludes that the primary way in which existing design tools are limited is by their complex modeling environment, restricting access to energy analysis at the early stages of design. Many attempts have been made to overcome the limitations of each system and creatively merge the competitive advantages of each, proposed through interdisciplinary integration of existing tools. The conceptual design phase holds all the potential for performance based design to reduce energy consumption and improve thermal comfort. The aim is to create an easy-to-use platform to support architects, tailoring to their needs and the ways in which they work through design problems.

This thesis proposes a new conceptual framework for a digital design tool, introducing energy and cost analysis to the earliest stage of the design process. The 'Passive Architecture Tool for Exploratory Design' supports informed design choices through negotiation between design options at the intersection of main considerations of design, energy and cost, offering the opportunity to develop performance based design methodology. Modeling and simulation are integrated in a cross platform game engine to allow quick and intuitive development of design proposals and encourage analysis of passive solar systems at the conceptual design phase. Cross pollination of tools reorganizes the way in which we think and interact with designs and their related information. Multiple iterations will shed light for the user on the interdependencies; collective learning will facilitate a local culture of sustainable thinking around low energy climate sensitive solutions, striving towards wider collaboration and participation in design production.

[3.1 TARGET DOMAIN]

Tools must respond to the nature of the project at the time in which they are needed. It is most time and cost effective to equip designers with adequate tools at the inception of the project. During early simulation there is little information available, but speed and flexibility are critical for brainstorming and exploring ideas. By detailed design, simulations are resource intensive, difficult and time consuming to use, resulting in a single design developed and analyzed, missing the opportunity for comparison. The cost entailed with software includes, the licensing fee, training cost and cost of use in labor hours. The ideal tool would require little input from users, and a quick 3D building sketching system that allows custom forms and components that would offer comparative feedback. "Choosing an `overpowered' [building simulation program] is not only unnecessary and expensive but can be costly when mistakes are made due to the complexity of the software.[104]" As defined by user preferences accuracy is not of critical importance, but the targeted domain would integrate intelligence with usability (Refer to Figure 12). As such, it would be better utilized for comparative analysis and developing an understanding of interdependencies.

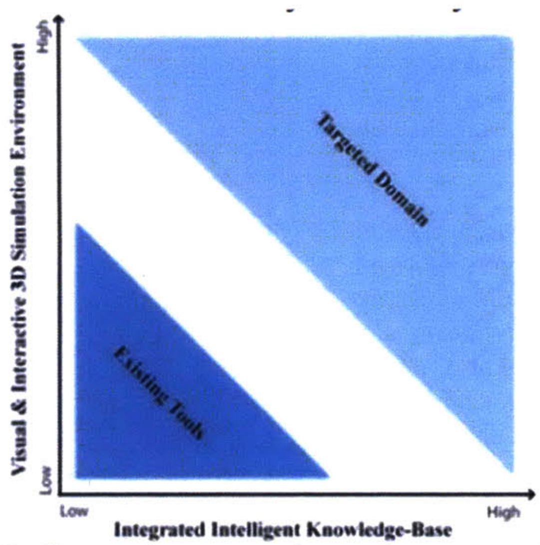


Figure 11: The gap between wishes and existing tools
Source: Attia & de Herde, 2011

The conceptual design harbors "the definition of design objectives, the creative generation of solutions, and their judicious evaluation to assure their satisfactory response to the defined objectives."[105] Climate-zone-specific energy-performance criteria for heating and cooling can guide designers toward cost-competitive levels of investment in passive measures in balance with other conservation measures and renewables. The simulation will offer insight into embodied vs operating energy, to reveal hidden costs directly proportional to operating costs for ease of translation into savings. Embodied energy and cost effective building materials in the building construction can significantly reduce the overall energy consumption and investment. The greatest percentage of the total energy use in the building life cycle is represented by the energy necessary for the use and maintenance of the building and the energy put into the building during construction. Studies show that for conventional buildings the operational energy is 85 - 95% of the total energy use over the lifetime of the building[106].

Doha's housing market has been affected by an acute shortage for years. The number of households has risen considerably in recent years, due to a sharp rise in the growth of the population, but there remains little or no vacancies in the market. The housing shortage in 2014 is at 37%, approximately 47,500 homes, expected to drive up further to 85% in 2018,[107] making it a potentially influential sector with 100,000 housing units expected to be added to the building stock by 2020.[108] For purposes of the prototype development for this context, it will be targeted towards architects as leaders of the design process. The strict regulations in Qatar limits informal settlements and necessitates the use of professional architecture services to obtain building permits. This thesis proposes that reform of professional practices by adapting the early stage design workflows could be a route to building a more active culture around using low energy solutions to reduce energy demand. This will not replace the need for architects to additionally assess other critical variables for each project, nor the need for detailed energy and cost modeling at a later stage in the design, but this should have the primary role to optimize design as early as possible.

The impact of demand reduction in the residential sector will only be feasible if adoption of passive strategies happens at a wide scale, necessitating reform of the local professional culture. The integration of local building knowledge with emerging technology, hopes to induce an architectural language of critical regionalism that is relevant for both time and place. Piedmont-Palladino discusses the implications: "The potential to change the very culture of building, however, brings with it additional challenges. Technological opportunity precedes the underlying change in the culture of a design and practice that it will catalyze... It is no small matter to change roles, responsibilities, and processes that have been in place since the Renaissance. But in an industry ripe for reform, the change is worth the risk. The newest technologies offer a profound transition from the ancient

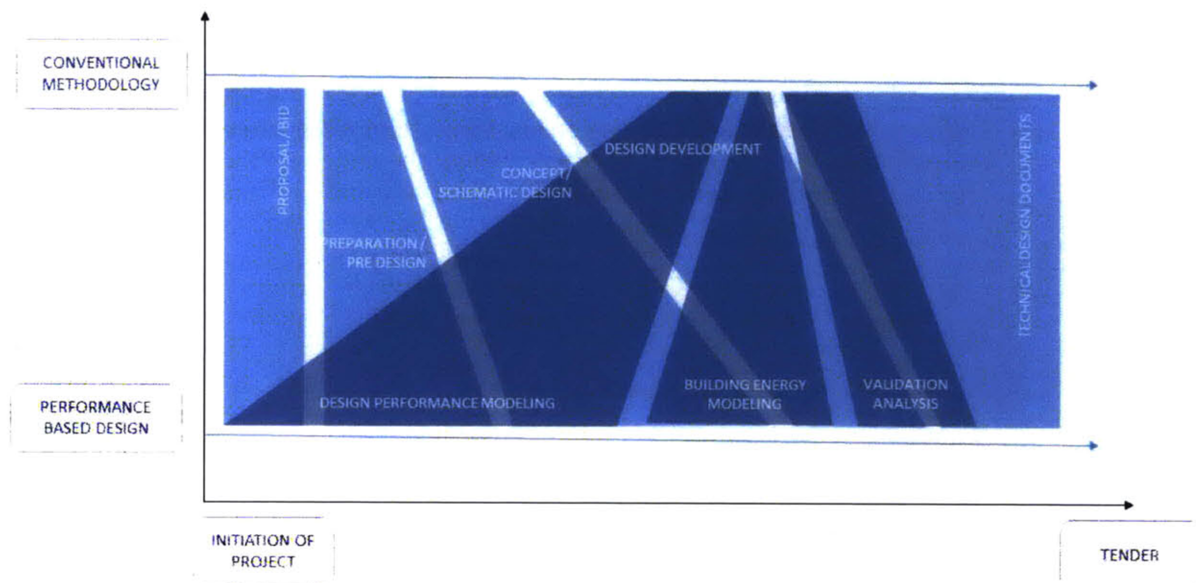


Figure 12: Performance Based Design Methodology vs Conventional

Source: Adapted from American Institute of Architects "An Architects Guide to Integrating Analysis into the Design Process", 2011 traditions of drawing to building; our imagination must be applied not just to the design of buildings but also to the processes that create architecture itself."[109] Changes to design practices can be instigated by a design tool, regarded as "socio-cultural" force, "rather than merely a technical issue.[110]" The change in culture towards passive design is predicated on a revised design methodology that embeds performance into the conceptual design phase. The tool offers the potential to shift energy simulation to the start of the design process to influence significant design decisions. The suggested methodology in Figure 12 shifts time and resources to the start of the project, expanding the role of analysis to be incorporated at every stage.

Successful design tools need to facilitate collaboration between all stakeholders[111] and assist designers in making decisions and communicating them, by presenting the principles behind the best variants or facilitating understanding of the impacts of different alternatives[112]. It is intended that platform could introduce design to a wider audience, making intelligent digital design tools accessible and demystifying some of the drivers for decisions. This would allow greater levels of participation from homeowners, policy makers or contractors, though to take advantage of the expanding and customizable nature, the tool could be easily adopted into office workflows.

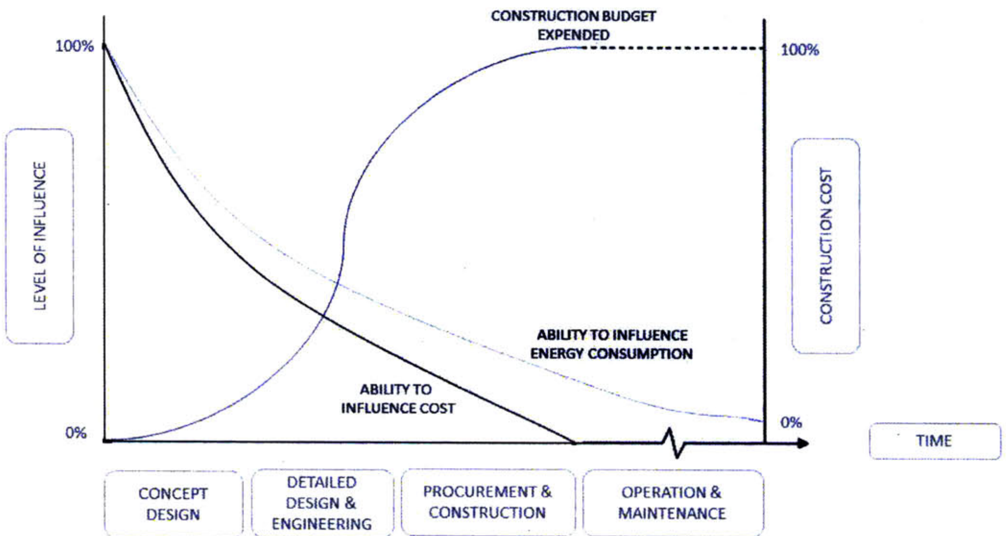


Figure 13: Ability to Influence Construction Cost over Time

Source: Adapted from Sketch Plus / Organizing for Project Management

[3.2 OBJECTIVES]

[PERFORMANCE BASED DESIGN]

"Performance based design consists of explorations supported by strategies to generate and analyze alternatives that address challenges with specific objectives: a framework to describe design as exploration through objective, alternative, impact, and value spaces."[113] It should be accepted that the greatest opportunity for a design to strike the balance between the highest performance, lowest cost, and any other requirement exists at the earliest stages of development. Referring to Figure 13, 70-80% of the cost is said to be committed by the end of the conceptual design stage. Therefore, it is essential to estimate and optimize costs as early as possible since any changes at a later stage usually incur additional penalty. The ability to compose multiple, competing concepts, and then evaluating the system-level performance is what is required to realize the potential for informed decisions in early stage conceptual optimization. This period of the project is usually severely constrained by information, time and money, so there is a need for quick feedback with limited data. Evaluation of cost sheds light on the implications of various design changes, while also allowing better assessment of overall economic feasibility. This provides the architect with rational scientific basis for evaluation and communication at a time of high flexibility and leaves possibility for validation through more extensive analysis at a later stage.

The aim is to use realistic predefined information during the early design phases, where the data available is often vague and incomplete, with the option to vary settings, and navigate between possible solutions to evaluate technical performance alongside special qualities. Legibility of a design and its components makes decision-making process more transparent, effective and understandable. Simulation tools provide the designer with additional information that can inform the design but the subjective process of assessment, evaluation and exploration remains in the hands of the architect, refer to Figure 14 for proposed workflow. "One can imagine this as a creative cycle in which the computer provides real-time objective feedback on a variety of relevant issues, which can in turn inform the direction of the architect's design decisions until the boundary between sketch, simulation and analysis blur into a continuous, creative design process"[114].

The goal of design in architecture is to achieve the best balance of performances in a complete set of criteria[115]. Parthenios[116] identifies 'Critical Points for Change' as the moments in which the design reveals something that triggers the architect to revise and enhance the design. He posits that computation tools can assist the user to maximize these occurrences in one of six ways: "a) to reveal the CPC earlier in the process by allowing the architect to better visualize his design ideas, b) provoke more Critical Points for Change, thus offering the architect the chance to improve his design, c) encourage deeper exploration of each alternative by offering additional levels of vision and understanding, thus supporting the decision-making mechanism for quicker and more coherent judgment d) support the architect in the dilemma of whether to alter an idea or abandon it and start again from scratch e) organize the different ideas that the architect has explored and present them in a broad palette f) better integrate the different media and tools in order to reduce the inefficiencies that CPC causes"

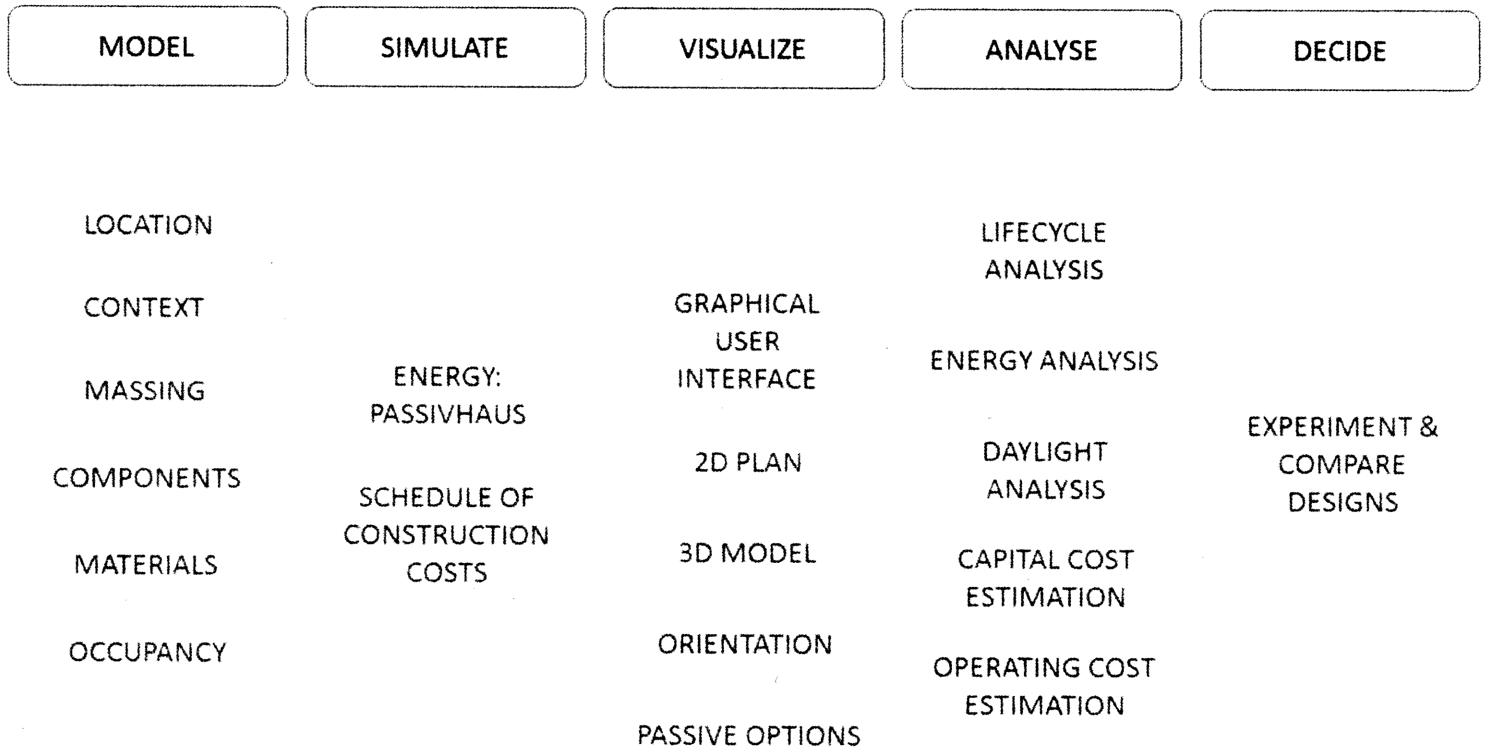


Figure 14: Proposed Tool Workflow

[PLAY TO LEARN]

The differentiating feature of this tool is the interface. Most simulation tools come as an added extension to existing 3D modeling software. Instead, serious games incorporate elements from video games to engage users in learning experiences in more creative, social and playful ways, Serious games have been traced to as early as the 1950s, serving a wide range of purposes such as to illustrate a scientific research study, to train professionals and to broadcast a message[117]. Prensky[118] promotes game-based learning through the inclusion of the following six factors: rules, goals, outcomes and feedback, competition, interaction, and representation.[119]

By incorporating more play and additional gaming features it could easily be translated into a package for a general audience to better understand the relationship between buildings and the environment. The potential of play to engage a user has been the focus of many efforts to reform education to better suit the way we learn. It makes sense to for video games to be emulated, as they are able to engage for users endless hours exploiting their ease of adoption for behavior change by creating immersive simulation of spatial experiences.[120] Education is forecasted to go through transformational change in the near future. Foxell & Mitchell [121] believe it is now driven by the "need for cross-disciplinary creativity and facilitated by affordable ICT," in addition to being necessitated by increasing globalization and climate change. "It was the potential of ICT that fully enabled the project of transformed education / personalized learning..."

Game environments, such as those created in Unity3D, are powerful in allowing careful and accurate drafting of designs that is necessary during the detailed design stage, so these tools intend to build upon an existing model, minimizing rework. The limitation is that this process requires a large amount of time and resources that isn't available at the conceptual design phase. By utilizing a video game environment, the simplicity and accessibility allows for architects to explore design variants analogous to digital sketching with indicative performance evaluation for priority criteria that can feed into the design decisions. The techniques used in the design of video games represent an enormous, untapped resource that could be used in creating new types of design tools.[122] Already they are being picked up as the next generation in architectural visualizations for walkthroughs and interactivity since they share similar platforms such as Maya and Blender. Using games can help lower aversion to failing, promotes engagement in an educational resource, supporting interactive learning and provides opportunity to apply knowledge in next iteration. Games also benefit from ease of use and generally involve little time to learn mechanics compared to CAD tools, and can be understood without aid of manuals or tutorials, etc.

[3.3 DESIGN TOOL NEXUS]

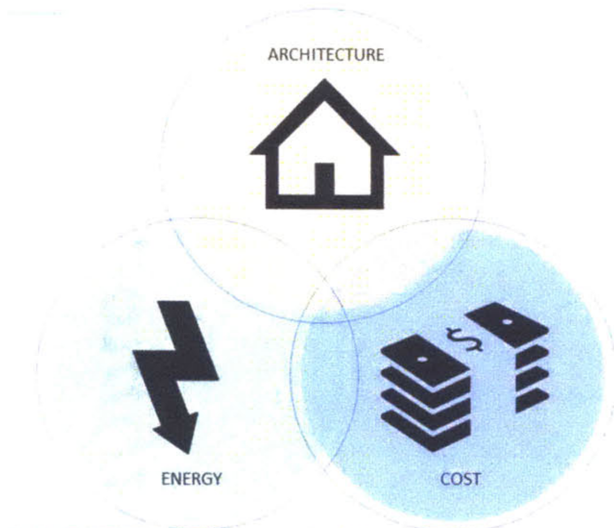


Figure 15: Conceptual Framework

The architects early design process entails "the definition of design objectives, the creative generation of solutions, and their judicious evaluation to assure their satisfactory response to the defined objectives." This thesis identifies the single family home as a key sector for future development, and proposes to aid design decisions to embed passive solar cooling into the conceptual design of the building envelope. However, It is understandable that financial constraints play a critical role in design decisions, therefore, there is opportunity for both energy and cost performance to be evaluated simultaneously, as per Figure 15. Negotiating between these in a single interface for quick iteration and comparison that explores the design space (defined by all possible solutions to a given design problem) in search for well performing solutions and demonstrates dependencies for a toolkit of solutions that can improve energy performance. The sources of analysis are summarized in Figure 16. If passive is to become a standard mode of construction, it must be widely accessible and able to educate users that passive strategies do not necessarily incur significant financial investment. Estimation of upfront costs against lifecycle costs helps us visualize that triple-pane windows and added insulation may add costs upfront, but these expenses are offset by the smaller air-conditioning systems that passive houses require.

[3.3.1 ARCHITECTURAL DESIGN]

The early design process is characterized by a search for new possibilities, where architects generate many diverse solutions, usually hand sketching ideas that are later transcribed to CAD. Building a model as "imagery management" is argued to have benefits: A three dimensional material or digital representation, allows increased perception and allows a designer to "utilize the fluidity of imagination.[123]" The complexity of even an early design model requires it to be constructed in steps, and each step in the construction process results in a model state that itself represents a possible building design. At the crux of the theory is that the process of constructing a model is therefore a process of implicit option generation. Conventional tools are insufficient in that they are unable to

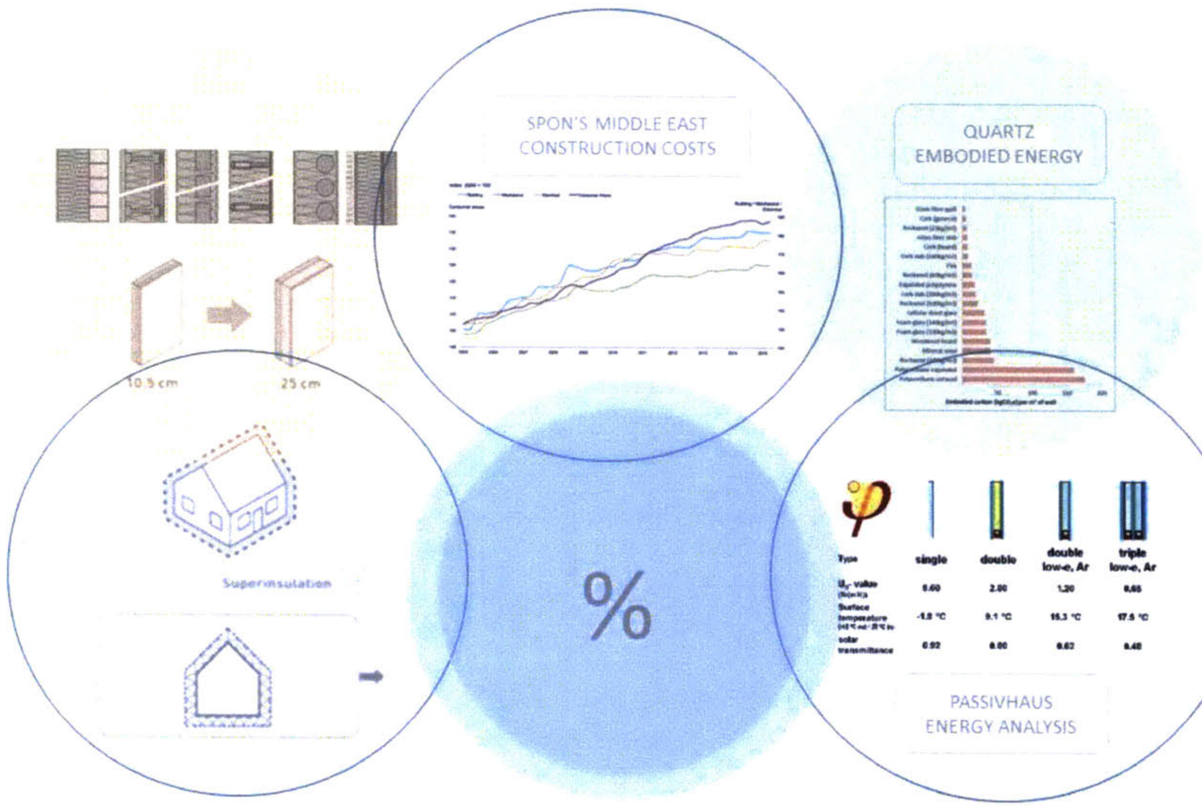


Figure 16: Exploded framework: Sources of Analysis

convey time in addition to the 3 axis but also the ability to navigate freely through the designed space. Real time sensorial perception of spaces. Immersion is a psychological state characterized by perceiving oneself to be enveloped by, included in and interacting with an environment that provides a continuous stream of stimuli and experiences.

The tool encourages learning about abstraction and representation, the relations between form and meaning, the manipulation and ordering of space and form, and the sense of grammar in design. It emphasizes architecture as a dynamic, via the idea of people moving through and between elements, rather than static externalized experience. They operate at the edge between abstract forms and compositions that can be recognized as possible elements in a built environment; part of the value is the imagination of looking through windows, walking past building masses, or being inside spaces. As we move towards an age of 'virtual reality', the architect assumes a presence in the digital world at a scale relative to his or her designs, with "the workshop inhabited by the designer."[124]

Building energy analysis requires an abstracted model of the physical world into materials, properties and heat transfers. Though several tools offer cost-benefit analysis tailored to the various stages of the design process, there are two primary methods by which the user produces digital architectural models: freedom of form vs restricted. The first usually takes place in a CAD software, while the latter generate an approximation of the building from a series of user defined inputs. CAD software sacrifices speed for accuracy, while generated models are quick but restricted by the flexibility to making complex geometrical masses. As a result, neither are congruous with the early architectural process by disconnecting from the process of quick iterative design.

The essence of 'games' lies in a person's immersion in play subject to rules. The rules in this game emulate the microcosmic world of design & construction. Armed with a range of prefabricated components, first you must build according to rules: these are the conditions for the components. For example, columns must be placed at corners or regular intervals, though the free column can be placed anywhere on the ground plane. This provides freedom when exploring design options that have non standard structural systems. Columns, for example, can only be placed on floor planes, while vertical elements such as doors and windows, require columns to be placed between. The complexity of the simulation increases when the user goes beyond the basic component set. They can modify sizes and materials to have greater control and flexibility over exploring alternatives in a friendly interface with simplified options that reflect the local market supply. Passive systems can either replace or be overlaid onto basic components. For example glazing shading and green roofs can be placed on top of existing components, while thermal mass and insulation require rebuilding the component. The components are just as easily destroyed as instantiated, though destruction may have further consequences for the stability of other components. The intention here though to be able to quickly produce multiple proposals side by side for comparison. The database of components can be edited to some extent manually real time in the game, or if a user wished to develop their own components, can model in a standard 3D CAD software and add to compendium. If the tool was given networking capability, users could save components to the global database increasing options for prefabricated components.

Joining components creates building groups that are used for evaluation of designs. This means that all parts of the model must be joined by components to be considered a single model. Analytics on building groups are based on proven, rigorous forms of assessment, but should not be the sole source of estimating. The lack of detail in the model will be reflected in the analytics, instead, these values should be reviewed in a comparative lens to identify potential areas of optimum cost-benefit. The units of these analytics must be understandable and comparable, possibly necessitating interpreting of values through percentages or adjusting orders of magnitude. Analytical data user preferences are touched upon briefly during user surveys, however this topic an extensive area of research outside of the scope of this research.

All simulations, require an abstraction of real world data - to be able to define and describe in values a quantifiable model on which measurements can be made. In the process of extracting information, details can become obscured or irrelevant. Therefore in the absence of air movement studies, natural ventilation is difficult to quantify and cannot be included for the purposes of this study. Further, for example, while shading can be evaluated as part of a model - the flexibility and advantage of the system is an indefinite number of options for customizability but the model will be limited in so far of how it translates these and may not then be able to differentiate the different variations beyond a percentage of covered or uncovered area. Passivhaus contains a much higher level of abstraction than more sophisticated tools, which for the purposes of a prototype for early stage modeling, is acceptable. If the tool is successful in stimulating a change in behavior from designers, development of the next version could consider substituting the simulation engine with one that is able to evaluate further geometries or intricacies of a more detailed model. Though caution should be exercised as accompanied with higher accuracy for simulation is the need for more detailed input from the user.

[3.3.2 ENERGY]

The primary interest of this thesis centers on encouraging passive design as low energy demand management strategies. After searching for an appropriate standard on which to base analysis of energy performance, the Passivhaus is both a standard and a measurement system that uses a spreadsheet for quick, approximated values with low computation time. In 25 years, over 40,000 buildings have been constructed with Passive House becoming the most tested and rigorously verified building standard, exhibiting savings of up to 90% in energy consumption. Qatar's Passivhaus, a pilot test project initiated in 2012 saw the construction of both a Passivhaus villa and a Business As Usual (BAU) villa side by side to test the Passivhaus system alongside an identical control building (conventional), both inhabited by small families with young children and monitored for 3-5 years.[125] The primary project objectives was a 50% reduction in annual operational energy consumption, water consumption and CO2 emissions, while adding no more than 15-20% of the BAU capital construction cost[126]. Passivhaus allows a large degree of flexibility in how the standard is delivered with just three criteria stipulated: heating, cooling demand or load, airtightness and total primary energy demand.[127]

While many rating systems compensate the high energy demand with efficient systems and clean energy sources, the Passivhaus standard focuses on form and material to influence operating energy demand. Depending on locale, a Passivhaus typically uses only one-tenth as much energy for heating and cooling as houses built to current codes. Since building to Passivhaus standards involves creating a virtually airtight building, often heavily insulated, not only is temperature regulated extremely well, but outside noise and entry of dust is almost eliminated. Though it is not without limitations. The surface area is where a building loses heat, and by ignoring the carbon that goes into materials and construction, and because as any geometric shape gets bigger its surface-to-volume ratio drops, it favors larger buildings over smaller ones. However, the nature of larger buildings to have their energy less affected by the skin, means that Passivhaus is more applicable to surface dominated structures, applicable for small residential buildings. It has also been argued that the Passivhaus standard should be further differentiated for hot and cold climates, so it can take into consideration particular strategies for arid regions such as evaporative cooling that may have a greater impact than high thermal mass. Has a higher level of abstraction - so fine tuning changes may not be reflected in calculations. Nevertheless, for the purposes of this project, the Passivhaus spreadsheet can serve as an adequate basis for the evaluation of energy performance. The option always remains for future versions to replace the simulation engine that drives it.

While Passivhaus standard concentrates on minimizing energy in use, it neglects to consider the embodied energy of materials used or their lifecycle environmental impact. To accommodate this limitation, we use the Quartz material database to conduct assessment on the composition, health hazard and environmental impact data for building products. A truly 'sustainable' building must consider not just the operational energy outcomes, but also the type of construction and the required specification improvements. A further reduction in life-cycle embodied energy is the maintenance and durability impacts of designing to the Passivhaus standard. These buildings are designed for longevity, carefully considered to eliminate condensation and mould, usurping issues like rot and degradation of the materials hidden within the construction.

Also the Passivhaus standard was initially developed for heating dominated scenarios, and while active cooling algorithms were tested with some projects in Mexico for cooling dominated projects, it does not account for variable climates, Other limitations of the abstraction of the model could be that it may not be able to reflect the impact of minor changes/details in the building design. Though Passivehaus claims to be applicable for both heating and cooling dominated environments, a study of the Passive House principles for the Saudi Arabia found that it may be more energy efficient to implement a Passive Evaporative Cooling system which relies on air flows: direct or indirect natural ventilation, that would be cooled by the evaporation of water but would mean the building would not be able to be airtight. However, is this really preferable in environments with poor air quality? This is indicative of the larger problem of the need for the development and verification of systems particular to this environment. The standard itself operates on the verification of meeting a certain threshold, a single fit for all evaluation necessary for accreditation, however since the tool is focused of looking at the relationships, it will use the calculations to demonstrate relationships but will set relative targets rather than absolute metrics.

The focus of Passivhaus is not only about ultra-low energy consumption. It is also a build quality, indoor air quality and thermal comfort standard. One should approach the myth of Zero Carbon with caution. Zero carbon homes often rely too much on renewable sources to offset use rather than eliminate excess consumption. The focus should be on reducing the building's energy demand by "getting the fabric right", to then also reduce the need and cost of adding renewables to reach zero carbon, leaving the option available should a client wish to and should site conditions permit. Combining passive building principles and low peak load design tenets with a zero energy target has an intrinsic logic: reduce demand and peak loads to a point at which the envelope improvements are cost-effective and all the building's needs can be met with a minimized and affordable and active renewable energy system to reach zero energy. Praznik defines the most important measure for decreasing the amount of operation energy necessary is to increase the energy efficiency of the building with higher performing thermal insulation throughout all components while maintaining an air tight thermal envelope free of heat bridges, concluding that the optimal type of energy efficient home is, in fact, the passive house.[128]

PASSIVHAUS TECHNICAL REQUIREMENTS (Cotterell & Dadeby, 2012)

1. Airtightness 0.6 air changes per hour at 50Pa (positive and negative) pressure
2. Annual Heat and Cooling Demand: 15kWh/m^2.a (kWh per square meter per year needed to provide space heating to 20C, or cooling in hot climates)
3. Maximum Heat and Cooling Load: 10W/m^2 (maximum power needed to maintain 20C internally when it is -10C outside)
4. Primary Energy Consumption: 120kWh/m^2.a (kWh per square meter per year needed to meet all energy demands, energy defined as consumed at source, e.g. heat extracted from fuel at power station)
5. Ventilation: 30m^3 per person per hour (needed to provide fresh, healthy air to building occupants)
6. Minimum Internal Surface Temperature: 17C (lower surface temperatures cause convection driven drafts; this target avoids this allowing all parts of the building, even those adjacent to windows to be used)

To achieve these standards, walls, roof and floor - the components that make up the "thermal envelope" - need U-values of 0.15W/m^2K or better, depending on the form of the building - less efficient building forms require higher performing thermal envelopes to achieve the standard. Windows need overall U-values of 0.80W/m^2K (0.85W/m^2K installed), along with other characteristics, such as low psi-value spacers, good frame U-values, high g-values (also known as Solar Heat Gain Co-efficient).

Passivhaus buildings are 'effectively' thermal bridge free. This means psi values of less than 0.01W/mK. This is achievable with careful design and double all-round gaskets for air-tightness

[3.3.3 COST]

Carbon abatement has several economic challenges hindering progress, such as lack of awareness of potential cost savings, agency issues such as in Qatar when builder and occupier are distinct, and financing hurdles and rapid payback requirements for up front investments[129]. Cost has been introduced as mechanism to satisfy budget conscious stakeholders in finding solutions that demonstrate significant energy savings that can payback the initial investment cost. One of the most common responses to why passive design is not implements is that costs are too high. While the incremental cost in the U.S. has been quoted at 5% to 20%, the incremental cost in Germany, where Passive House has been practiced for well over a decade, it has been driven down to between 3% and 5%.[130] Meanwhile a square meter construction cost comparison does not account for lower operation and maintenance costs. We cannot dismiss that fact that ultimately many design decisions come down to a question of economics. Cost – benefit analysis in this case is therefore beneficial to communicate the tradeoffs between upfront costs and savings in operating. This provides transparency and rational support for decisions with a higher level of information. Passive design may not be a client's top priority and architects have struggled to communicate the value of such strategies in the face of cost adverse clients who are often not the residents and therefore willing to offset costs onto the end user. The phrase "Tunneling through the cost barrier" implies saving enough cost on the mechanical and heat distribution systems to offset the increased investment in the envelope and enclosure. Fuel prices will play a role in determining the payback time for these up front investments. The following tables show the factors affecting initial and operating costs relating to sustainable features can be increased or decreased.

Factors affecting initial sustainability costs[131] (Rearden, 2013/Horne et al, 2011)

Increase of initial costs	Decrease of initial costs
	Smaller, smarter floor plans reduce construction and purchase prices
Insulation, advanced glazing, solar hot water service, water tanks, environmentally preferred materials, advanced technologies, etc	Thermal efficiency requires smaller, simpler heating and cooling systems
Premiums charged by builders and tradespeople unfamiliar with sustainable features	Water efficiency reduces hot water service size
Initial low demand for 'new' or specialty products	Innovative lighting design requires fewer light fittings
Carbon price of energy-intensive materials	Economies of scale for sustainable technologies
	Reduced urban sprawl lowers energy, water and road infrastructure costs
	Lower overheads (energy and water), 'green' discount loans and rebates improving repayment capacity

Factors affecting ongoing sustainability costs (Rearden, 2013/Horne et al, 2011)

Increase of ongoing costs	Decrease of ongoing costs
	Need to own fewer cars and drive less when living nearer to amenities
	Lower energy and fuel bills
	Reduced carbon cost premiums
Marginally higher maintenance for solar hot water service, rainwater tanks etc.	Improved indoor air quality reduces health costs and sick days — especially for children
Water pump operating costs	Improved thermal comfort increases enjoyment of home lifestyle
Some environmentally preferred finishes require more frequent re-application	Accessible design accommodates all life stages including temporary disability and ageing
	Lower maintenance costs for durable, sustainable materials and finishes

According to Barry & Paulson, there are four common types of preliminary estimating methods: time-referenced cost indices, cost-capacity factors, component ratio, and parameter costs[132]. All use past project data and order of magnitude scaling factors to predict a new projects cost. Provided there is sufficient information, approximated quantities are regarded as the most reliable and accurate method of estimating. An experienced surveyor can conduct measurements using fairly quickly using composite rates to save time, with methods that are not definitively standardized and tend to vary slightly from one surveyor to another.[133] Rough quantities will be extracted for the building materials to calculate estimated capital and operating cost per square meter to reflect local prices. Variances in operating cost will be mainly reflecting reduced costs from improved energy, with a moderate base to reflect operational and maintenance costs. Designers, consumers and builders should therefore cost a range of scenarios to determine the most cost effective housing solutions in their climate by varying the contribution of thermal performance, appliance efficiency, renewable energy and water efficiency. With the exception of efficient user behavior, sustainability improvements are among the few housing features capable of reducing operating costs. This highlights the importance of long-term thinking when considering affordability.

[3.4 VALUE PROPOSITIONS]

The proposed tool intends to support user needs and an improved design methodology in the following ways:

Front loading performance into a design has the potential to minimize rework. Competitive and cost pressures can force firms to condense entire projects, including bypassing conceptual design and working on design details from the get-go. This approach has severe consequences later in the project, when slight modifications to the design become time-consuming and expensive, and even lead the designers to deviate from the customer specifications to meet project deadlines. Agile project management. Conceptual design also supports the current trend of agile project management techniques, which focus on breaking down a project into smaller deliverables. Conceptual design tools often allow users to tackle a complex design by separately addressing its shape, materials selection, physical and environmental impacts, and other factors — yet another way to identify and solve problems early and improve overall design. With the outside pressures compressing timelines, it is critical that designers can be as effective as possible by having tools at their disposal that will help them make early design decisions quickly and easily.

The free-form, non constrained geometric functions, intuitive user interface, improved collaboration, and free or affordable price point have all contributed in making conceptual design tools accessible to stakeholders within and beyond the design department. In addition, conceptual design tools are exploiting the current IT trends of cloud computing and mobile app development, further improving collaboration by moving the design process beyond the walls of a company. Nearly all conceptual design tools facilitate design iteration — and in some cases, even automate it — in ways that most conventional high-end CAD tools do not, moving towards a culture of optimization. This results in more and better options to consider at the earliest stages of development.

Improved collaboration with customers and other project stakeholders in the early phases of design results in less rework, higher customer satisfaction, and shorter project cycles. It also reduces changes late in the design process, including change orders. Conceptual design tools improve collaboration across and outside the enterprise by opening the design process to all stakeholders, rather than limiting it to designers, engineers, and architects. Conventional CAD, in contrast, is more technically oriented to conform to geometric and engineering constraints, presenting a significant barrier to collaboration with stakeholders who are not CAD users. The potential for use among a wider audience incites interdisciplinary coordination and community participation.

Like most full-fledged CAD solutions today, the tool will allow designers to incorporate existing models (such as parts, subassemblies, and products) from their own archives or sourced externally, developing personalized libraries, improving reuse, shortening the design cycle, and reducing costs. Parts recycling can be shared internally within a group or globally, amassing an infinite number of prefabricated parts for quick drop into a simulation scene. Combined with defined properties, initially set up of customized components may involve some time, but this cost reduces each time the user recalls it. Simplified choices, ease of use, and speed of iteration are critical for reducing time for early design revisions.[134]

[CHAPTER 4: UI / UX DEVELOPMENT]

This thesis is not proposing the creation new software, but integrates existing tools in a platform typically used to develop video games, to suggest an alternative approach to conceptual design tools. The Passive Architecture Tool for Exploratory Design qualifies under an emerging category of "serious games", adopting play mechanics for an engaging learning environment, transforming the player into a user. The intention here is not to demonstrate skill in computer programming, but to articulate one example of the conceptual framework as a functioning tool. To demonstrate full capability of this conceptual framework is beyond the scope of this thesis. Instead, a prototype equipped with basic functionality and interactions can be used to convey potential usability. The demo will be available as an executable file for the Windows platform, attached to the thesis on a CD. A word of caution though: the demo does not perform analytical functions at this time but proposes a methodology that offers synthesis of existing tools and feature. This combination serves to bridge between disciplines to support decision making around key indicators of design, energy and cost. This chapter describes user interface and user experience of the tool while introducing some discussion of potential capabilities of a complete version. Development of human-computer interaction falls primarily into two categories of user experience and user interface. The user experiences relates to the back end development of system structure and technical requirements. Meanwhile the user interface addresses the front end user interaction.

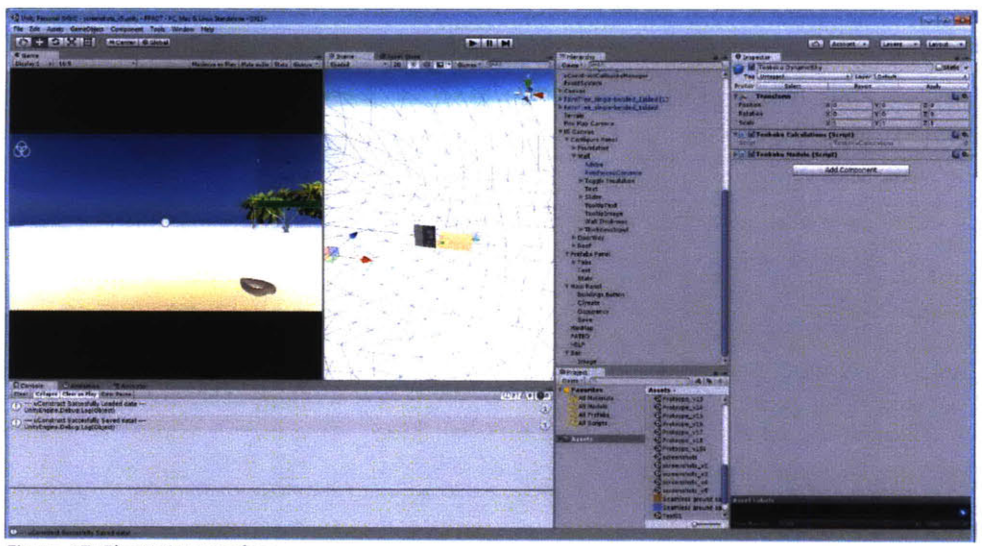


Figure 17: The Unity Interface

[4.1 USER INTERFACE]

[UNITY]

In recent years, gaming engines have quickly become recognized as industry solutions for rapid development of engaging built environment experiences. Borrowing tools from a growing industry with significant investment in emerging technologies, they have become the designer's latest tool of choice to create 3 dimensional architectural visualizations. Video games have long been incorporating building systems and construction logic into popular games such as in SimCity or MineCraft. It seems logical to adapt the engine into a CAD tool, to transcend the barrier towards creative manifestation of spatial ideas utilizing these same mechanics to allow the user flexible participation in the building creation and visualization. Unity is just one of many gaming engines that could have been used, such as Unreal Engine or CryEngine, all competing to create visually engaging player experiences for a range of platforms and operating systems for desktop, mobile and console. The platform's main task is to allow quick programming of a game in C# or Javascript. The Unity interface allows you to create scenes on a terrain in 3 Dimensional space with a vertical canvas in the Y axis holds the user interface components. Assets such as models, images and scripts are brought into scenes and perform assigned behaviors in the hierarchy upon specified user behaviors in the inspector. Switching into game mode allows testing alongside development, within a screen.

Affinity: Bring objects to life through good visual design: scale and materials
Availability: Make all objects available at any time
Encouragement: Make actions predictable and reversible
Familiarity: Build on the user's prior knowledge
Obviousness: Make objects and controls visible and intuitive
Satisfaction: Create a feeling of progress and achievement
Versatility: Support alternate interaction techniques
Simplicity: Do not compromise usability for functionality
Assistance: Provide proactive assistance
Personalization: Enable the user to customize an interface
Safety: Keep the user out of trouble
Support: Place the user in control

Figure 14: User Interface Design Principles, Thovtrup & Neilson, 1991

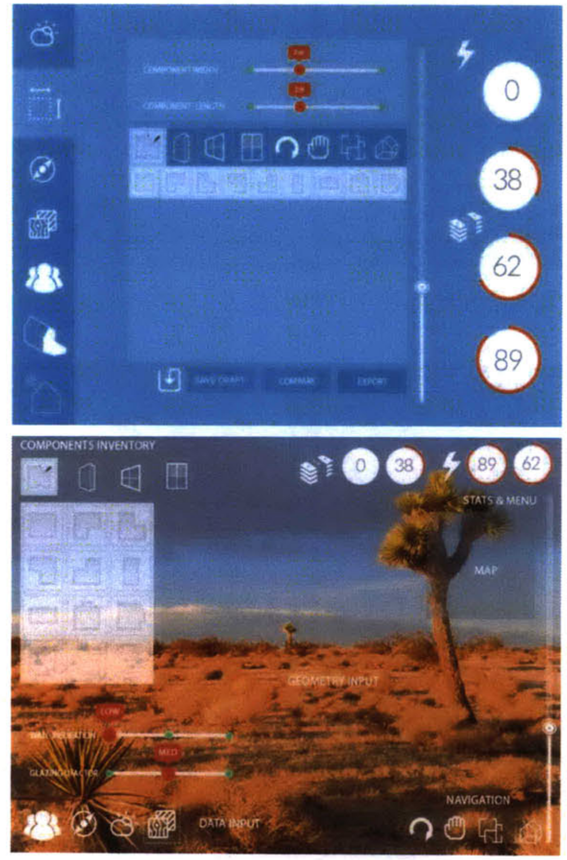


Figure 18: Interface design options 2D vs 3D

The platform supports 2D and 3D environments, and an initial mockup compares how these could be presented. The first essentially follows the same structure as existing CAD interfaces, containing the model in a defined box that would be difficult encompass field of vision. The traditional CAD interface hosts a central modelling environment that is usually flanked at most sides by toolbars. Detaching itself from this prescribed system, the proposed user interface seeks to take full advantage of placing the user in first person perspective of a simulated real world environment. Affinity to the interface will engage users and encourage interaction. To exploit the immersive nature of the virtual environment, menus are hidden until requested keeping the interface clean and providing a full screen to assume. In addition, a minimalist aesthetic is employed to simplify icons and reduce the need for any complexity. Extracted from the IBM Ease of Use User Interface guide[135], the user centric design will embed the design principles from Figure 14 into the interface.

[4.2 USER EXPERIENCE]

Figure 19: Changing sun position

[VIRTUAL ENVIRONMENT]

Video games have been perfecting graphics and modeling realistic physics and environments. The idea is for the user to be located within an environment constructed to reflect real world conditions as closely s possible. Creating a terrain requires heightmap data and satellite imagery. Several tools offer a Google Earth type of scrolling interface to be able to select any location globally. In addition, integrations with tools such as CityEngine from ESRI GIS can quickly develop contextual massing to populate an urban area the site may be located in. The full screen becomes the viewport to this landscape with expanding menus to access actionable features. This ensures relationships with the site conditions are immediately apparent, and by simulating a realistic dynamic sky day and night cycle, creating deliberate relationships with the sun becomes an obvious task, see Figure 19 for variances in sun position over the year. World and model exploration encompasses the entire screen.

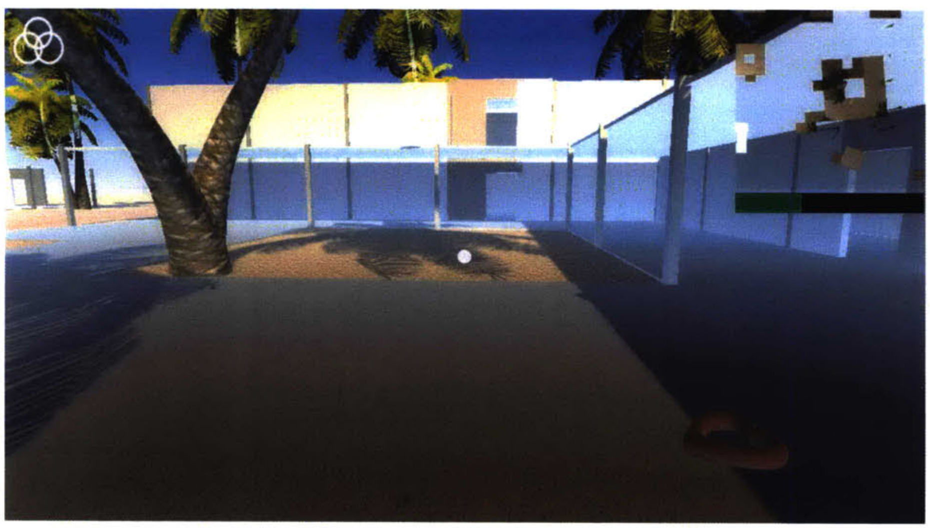


Figure 20: First Person Perspective: Navigate with compass and mini map on left side of screen

This immersive experience is a powerful visualization to connect design with site, in contrast to a blank paper or digital canvas. The graphical user interface (GUI) features such as menus, analytics, controls and buttons are overlaid and expandable bars expanding from the side of the screen. The screen size and GUI are set to adjust as per the display requirements to a wide range of screens. The user assumes a first person perspective set at the characters eye level, to be able to experience the site to scale, see Figure 20. A mini map window transmits from a second camera attached to the user, maintains them at the center of the map and offers a top view that widens the viewport at a distance of 20m above the character, intended to assist with navigating larger sites. Cameras can either be statically positioned or attached to objects to follow.

[NAVIGATION & CONTROLS]

User navigation follows traditional gaming convention with the keys W,A,S & D moving the user forward, left, backwards and right respectively, with spacebar to jump. The mouse rotates the user and adjusts. The needle graphic will update relative to a static North indication as the user moves position and changes direction, though there are many methods of indicating direction. A compass indicates the direction in which the user is moving and can take many forms, as a moving needle on a 2D image on the GUI or as in this case, as a floating 3D object whose point is constantly directed North. The cursor controls the location of input on the screen for menus or building – mouseray vs middle of screen. Hovering over some items may trigger additional information to be revealed on the interface. Clicking buttons on the interface initiates a contract to execute the attached action. While some actions are activated using a standard click function on the designated area of the screen marked by an icon, others require a different type of user defined input by interacting with sliders, number entry, drop down menus, etc. Deselecting a components by pressing Escape, allows the user to destroy components that it selects with a right click.

[ASSUMPTIONS / EXCLUSIONS]

- Abstractions: translating components into performance indicators is an approximation not simulation.
- Scale of buildings – this type of analysis is more suited to smaller skin dominated buildings.
- All values in the prototype are indicative only and have not been validated in any way.
- Analysis of daylighting and solar gain are excluded from the prototype
- The impact of surrounding buildings will not have impact on a building group's performance.
- Costs and material properties will be presented in a limited number of preset options to reflect local country standards.
- Passive strategies that are difficult to model and quantify have been excluded from the prototype: natural ventilation, evaporative cooling,

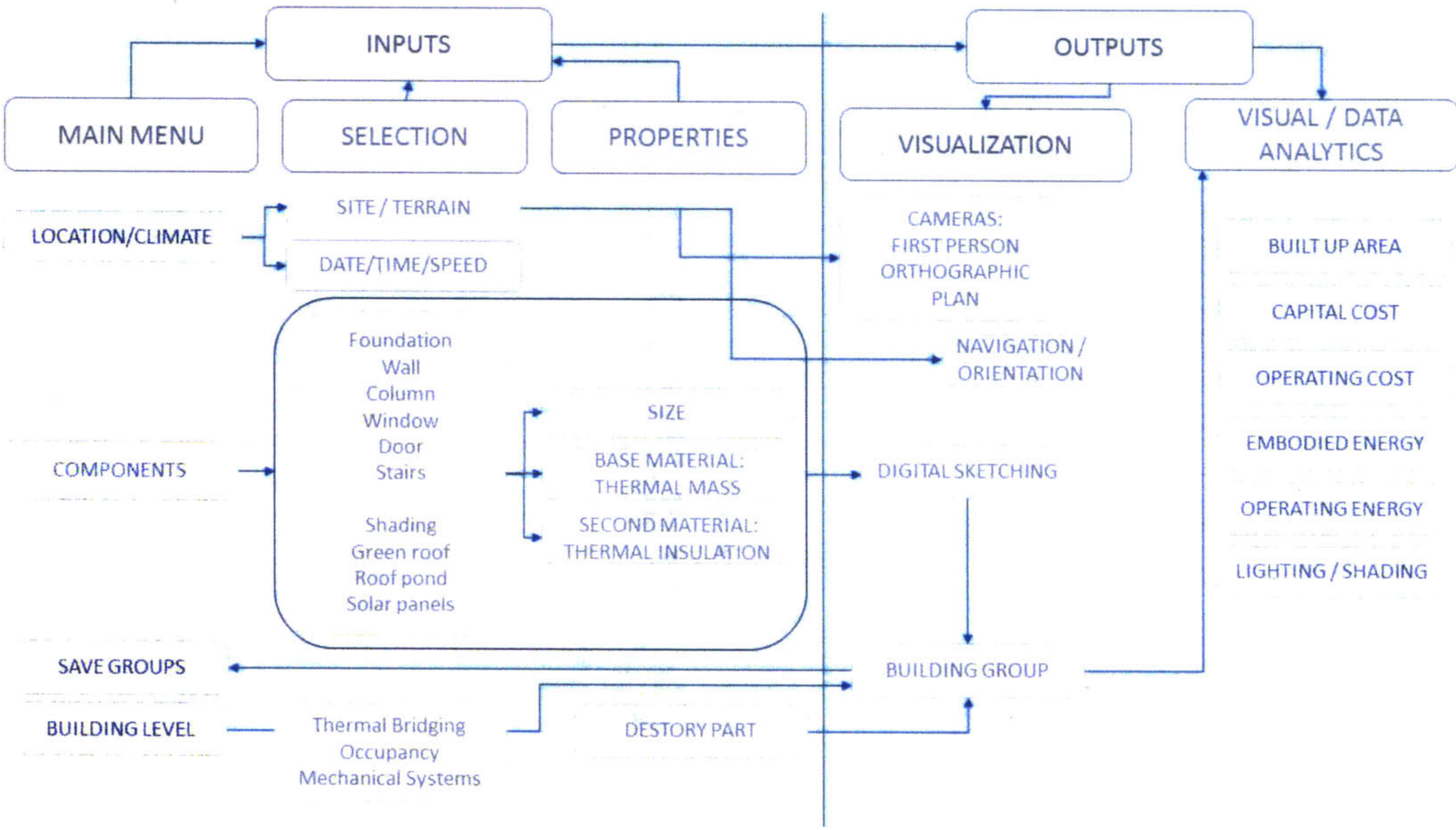


Figure 21: Information Management System

[INPUTS]

- Location : the sun position is specific to this latitude and longitude
- Building geometry orientation initiated through navigation, later extracted from the normal of elevations
- Insert components: Modify properties: change dimensions or materials
- Foundation: Modify size, material and insulation level
- Wall component: Modify size, material and insulation level
- Window is a shader of chosen size only able to be placed on a wall or ceiling. description as a percentage of the exterior façade – placed on wall or ceiling components
- Ceiling Material: Modify size, material and insulation level
- Roof treatments: overlay on ceiling component: green roof or skytherm options.
- Material selection reflects thermal mass
- Effect of air tightness and sealing thermal bridges at the perimeter or joints

[OUTPUTS]

- Visual and spatial feedback of model, scale and materials
- Built up area summed from floor components.
- Embodied energy of building materials from mining to site – Quartz Database
- Operating energy per sq.m – derived from Passivhaus calculations that sum:
  - Cooling energy required per sq.m
  - Lighting energy required per sq.m
- Capital cost of construction
- Operating cost – a reflection of operating energy results.

[4.3 BUILDING SYSTEM]

The envelope is the key mediary for heat transfer and target of passive strategies, particularly for small buildings such as residences which are generally 'skin' dominated buildings. Buildings experience heat gains and losses due to solar radiation, either absorbed by external surfaces and transferred to internal surfaces, by entering directly through an opening to be absorbed by internal surfaces or when radiation gained by a building is released back into the atmosphere[136].

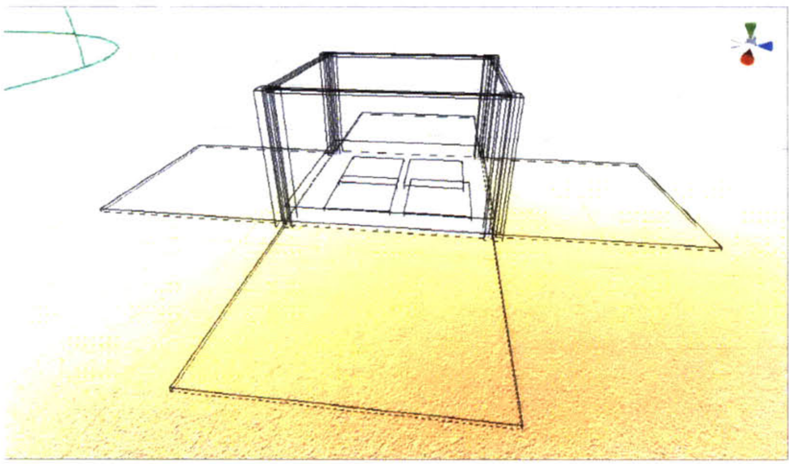


Figure 22: Objects that can be received for the foundation

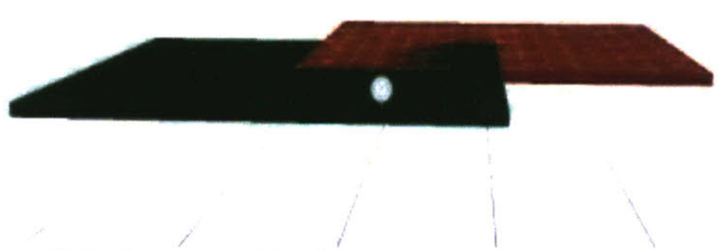


Figure 23: Feedback on acceptable placement of components

The building construction system utilizes prefabricated components to slot together, according to set conditions that dictate where they can be placed, into larger masses that determine the overall shape and size of a building. Placement can either be socket based or freely based onto a base object: either the terrain or another building component. Each component has rules that define where it can be placed and what it can accept, such as in Figure 22, shows the possible relationships that a foundation can accept. Visual feedback is provided to the user placement suitability, highlight acceptable positions in red versus forbidden locations in red, as per Figure 23. Many of these components can be scaled within Unity, giving access to a wide range of variations of a single item, so as not to need precisely defined components for each possible option. Instead it calls from an inventory an object to be modified, programming it to be scaled by a user defined value, by manual numerical input or selection from discrete choices. This also allows for greater customizability when dealing with predesigned components, necessary for design freedom and unexpected solutions. Components that lock together form a building group. This group is used as the basis for analysis and the relevant score is calculated live as the project is build and floats above it as a label. The score is instantaneously updated for different configurations to be displayed for comparison. Here, minimizing the surface area to volume ratio will improve energy performance by reducing the area of possible heat loss from the envelope. Visual feedback on if this an accepted location: red vs green. Area of interest reveals the different potential relationships for a component.

Each of the envelope components contains properties for each of the output analytics. When any of the properties such as size or material of the components are changed, this is reflected in the performance analytics. Components are imported to the inventory as .fbx object files: assets, and scripts attach to it to dictate its properties and relationship with other components. This means a user can design different components in most 3D modeling software and import it to the Unity inventory – single exercise to build a customized components library that can be later called on or shared. This can also include landscape features and furnishings to populate the space. The interface is set up to support runtime changes so that users can manipulate these objects to be scaled or apply change the texture, refer to Figure 24. This will reduce the number of components required and can even adapt the system to accommodate detail components, working from the brick scale, increasing time investment but increasing design flexibility.

[REPRESENTING PASSIVE]

Some aspects of passive design lend themselves easily to this the abstraction required by simulation models. With limited information the building will only reflect core and shell components. For example, choosing a material can easily translate into a u value or r value. However, the intricacies of building geometry may get blurred from a simplified model. Many proposals can have a similar Window to Wall Ratio (WWR) on a facade facing a specific direction. Passive design does not involve the use of mechanical and electrical devices, and so these are later considerations that do not affect the design but can have overall impact on building performance.

Figure 24: Choosing Component Size

Other factors are more challenging to integrate into models. Surrounding buildings will have an impact on the amount of solar radiation, daylighting, and air movement around a site. Urban layout can be utilized to improve the microclimate, with compact neighborhoods, and narrow winding streets to reduce dusty winds, minimize solar exposure to facades and create street shading. The use of a courtyard form will maximize shade and ventilation. In this prototype, building groups are examined independent from surrounding buildings, despite the benefit of region specific urban planning strategies. Similarly natural ventilation and evaporative cooling are difficult to model impact. Future versions should consider how these could be integrated for more climate or culture specific analysis. Below is a description of various passive cooling strategies and how they are represented in the tool.

[4.3.1 SITE & ORIENTATION]

The user is armed with a compass and map in a geo-located site with accurate sun cycles. Orientation must limit direct solar gain to the building to reduce heat gain while maintaining sufficient illumination of interior spaces so that daylighting can minimize the need for artificial lighting during daytime hours, reducing electrical demand. In general, horizontal surfaces will receive the highest intensity of solar radiation, followed by East and West facing vertical facades.[137] Orientation on a site is the first potential to limit solar gain, and recognition of its relative position helps to visualize locations for windows and where shading may be necessary. Effective space planning and strategic positioning of rooms can improve benefits from these climatic variances. The user orients themselves on a site relative to north, while post construction, the normal of the wall components is extracted from the model to determine the direction in which they face.

Figure 25: Material Settings: Thermal Mass & Insulation: Hovering over material icons provides more information

[4.3.2 MATERIAL CONSIDERATIONS]

Each component and its chosen material has embedded the energy and cost performance of that item. Predefined materials are chosen based on local industry standards. A criticism of existing sustainability ratings has been that they promote high performance materials that also have absorbed a high amount of embodied energy throughout their lifecycle. This misconstrues some claims of energy saving which may not so be easily offset when taking into consideration high resource costs for their production. Embodied energy is extracted from the Quartz database that brings transparency of building products and their impacts on human and environmental health. Users will have the option to select material, size, type and amount of additional insulation with visual feedback from textures and scaling, refer to Figure 26.

[THERMAL MASS]

Thermal mass differs from thermal insulation in that where insulation creates a barrier to maintain a temperature differential between differing indoor and outdoor environments, thermal mass on the other hand slowly collects thermal energy until reaching near the higher temperature until it begins to release this energy into the other space. In general, for a material to be good thermal mass and hold heat well, it must be dense, and must have thermal conductivity that is low without being too low. The high volumetric heat capacity and thickness prevents thermal energy from reaching the inner surface. When temperatures fall at night, the walls re-radiate the thermal energy back into the night sky. In this application it is important for such walls to be massive to prevent heat transfer into the interior[138]. Examples of good materials for thermal mass are rock, water, adobe, earth, mud, and concrete. In the tool, the primary structural material is considered to define the thermal mass. Figure 27 shows for walls, how the user selects the chosen material that updates the texture of the component. They can also define the thickness of the component, again offering visual feedback. Because the user is presented with a thumbnail of the material, hovering over the icon reveals more information. Simplifying options, inputs and interactions does not negate the amount of information available and shows how it can adapt to users of different skill.

Figure 26: Placing a wall in the scene: visual feedback from selections

Figure 27: Manual numerical input for wall thickness

[INSULATION]

The role of insulation is to essentially retard heat transfers through the building skin. It is measured in R-values, which are a function of the thermal conductivity of a material and its thickness Examples of materials that are good for insulation are fiberglass, rock wool, cellulose, and polystyrene or polyurethane foam. Windows require high insulation panels, gases or reflective films to counter heat gain from direct solar gain, to counter their poor insulating properties. Indiscriminate use of glass in hot climates wastes energy and creates uncomfortable living spaces.[139] Some research suggests that with adequate shade, the actual window size affects indoor temperature very little as long as it is shaded[140]. Insulation adds a concealed layer to a component to increase the thickness to wall. A slider has been proposed in this case to allow the user to navigate between discrete levels of insulation. Each notch on the slider represents different specifications of locally available insulation, with the worst and best thermal performers, occupying the low and high ends respectively. Again, as the user makes choices, more information is revealed.

Figure 28: Roof options

[4.3.3 ROOF TREATMENTS]

The roof is the single most important building component as it is exposed to the greatest amount of solar radiation, with usually little protection. Flat roofs receive exposure throughout the day and will receive excessive heat gains if not adequately protected by a double ceiling with air cavity or heavyweight construction for thermal mass. During the night, emissions to the sky effectively reduce the temperature and can be used as a source of cooling. Round domes, though less functional, always have a portion of their surface in the shade, allowing for heat transfer to occur within the material rather than towards the internal spaces. While ventilation in the roof space could be designed to remove trapped hot air, various other treatments are available to add additional protection such as roof ponds or green roofs, see Figure 28.

Roof ponds like the skytherm night radiation system exploit the specific heat capacity and thermal storage properties of water. Water needs over four times more heat to rise in temperature than either concrete or brick[141]. A study in Shiraz, Iran, demonstrated that for a 140 m2 one story house, the skytherm system is capable of reducing heating demands by 86% and cooling loads by 52%. [142]

Similarly, some places such as Toronto and Paris have passed laws that mandate all new buildings in commercial zones must be partially covered in either plants or solar panels. This can create shading, recreational space and provide scare urban area for planting fresh produce. The plants can contribute to the capturing of airborne pollutants and other atmospheric deposition, and filter noxious gases while adding an additional layer of protection to the roof where the majority of thermal transfers occur, increasing thermal mass properties.

Though they are all horizontal planes – the foundation, floor and roof are kept as distinct entities so that they can be used for the collection of information. The area of the foundations sum to the ground floor area, similarly for the roof. This gives them both different thermal exposure than interior floors and allows them to have different constructions. This kind of principle will apply whenever there are exposed and protected elements of the same kind so that they can be calculated distinctly. Users can be shielded from mistaking these by dictating the base conditions by which they can be applied. For example, to avoid confusion between foundations and floors, foundations can only be placed on the ground terrain, while intermediate floors require columns to be placed upon.

[4.3.4 DAYLIGHTING & SHADING]

The accurate sun cycles offers visual feedback on the interaction between form and light. Street lighting will be required during the night cycle to illuminate the scene. Lighting components are wall mountable and users can place them anywhere in the scene. However, without formal analysis there will be no validation of the proposal being exposed to too much solar radiation or if supplied with sufficient daylighting. Shading treatments are a viable option for overexposed glazing, particularly for the East façade, to avoid premature release of heat gains to the internal spaces. Windows can be placed into a building as part of a predefined wall component or if required for an existing wall, defined window can be punctured. This only applies a shader to the material in the specified area that renders the edges and transparency to appear as a window, so that it can be removed and relocated without affecting the base structure. Shading systems will each have different sockets and conditions depending on how they can be placed. Extruded shading is most appropriate above a window but could be a feature anywhere on a façade. Meanwhile blinds are exclusively placed on a window.

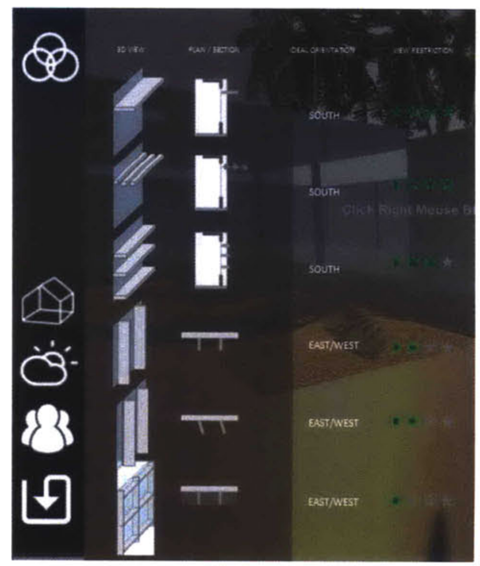


Figure: Window shading options and additional evaluative criteria

[4.3.5 AIR & MOISTURE TIGHTNESS]

Passivhaus buildings are 'effectively' thermal bridge free, sealing the envelope from leakages. The standard dictates psi values of less than 0.01W/mK, however it has been shown that some other strategies that would not be possible with an air tight envelope may be more applicable for this environment. A thesis examining passivehaus in Saudi Arabia concluded that a more porous skin combined with evaporative cooling demonstrated improved performance, suggesting there is still a lack of significant research specific to passive cooling for hot arid regions[143]. Thermal bridging is a detail and construction based feature making it difficult to translate into a component. Instead, the user could select from a series of low to high levels of thermal bridging for the building, to provide an indication of impact to performance by specifying these details. Possible visual feedback could be a change in color of affected edges.

[4.3.6 ACTIVE INTEGRATIONS]

The focus of the tool has been to encourage passive strategies, however, this does not exclude active systems from being considered in the model. At the macro building level, users can interact with Items such as occupancy patterns to see how their behavior can impact the overall use. Animating occupancy patterns over time with automated characters could help to visualize the impact of changing schedules. Similarly, checking the impact of different equipment efficiency ratings or changing the temperature of the air conditioner can become tangible actions for the user through cost-benefit analysis. At component scale, active solar collectors should not be shaded by nearby trees or buildings and should have solar arrays facing south. The solar potential of the roof could be calculated and solar panels become an additional roof treatment option.

[4.4 ANALYTICS]

Segregation of component types allows the cumulative areas to be calculated. In cases, where more specificity is required, other properties can be used for calculation purposes. Such as in the case of the walls that uses the normal to distribute facades according to orientation. Each group is given a raw score, reflective of a measured value for the following:

EE : Embodied Energy: MJ/kg : mega joules of energy needed to make a kilogram of product
OE : Operating Energy: kW/m2/a : kilowatt hours per square meter of Treated Floor Area per year
CC : Capital Cost: QR / m2 : Qatari Riyals per meter square
OC : Operating Cost : QR / m2 / a : Qatari Riyals per meter square per annum : correlated to operating energy

Meanwhile, since encouraging users to reduce operating energy is the main objective, the user is presented with a rating of how this proposal performs relative to the benchmark. Components must be joined together to be included in a building group for analysis. A saving system allows users to save building groups along with their raw data into an inventory for comparative analysis or quick recall. This would be an ideal format for users to share proposals. Metrics can be based on absolute or relative values as in Figure 29. For each configuration, the minimum and maximum performance for a set of components is calculated as the boundary values. The rating thus reflects the percentage improvement of a proposal from the baseline, typically representing the conventional building type, relative to the maximum potential for the same set of components.

Design of information management and data visualization are critical to ensure users are able to interpret their results and are guided towards better performing solutions. Providing the raw data above the building group as a label appears when the user is in close proximity to the group, and allows the user to quickly peruse an urban catalogue of built up designs for comparison, while duplicating this information in the menu ensures the user has access to it even when labels are not visible, eee Figure 30. Using values representative of measured performance is important so that interpretation is much less construed and abstracted. The rating system is a secondary form of explicit feedback as a static feature on the GUI ensuring constant awareness to coerce decisions that improve the rating. Analytics can be further utilized for visualizations and projections, or to set goals and objectives.

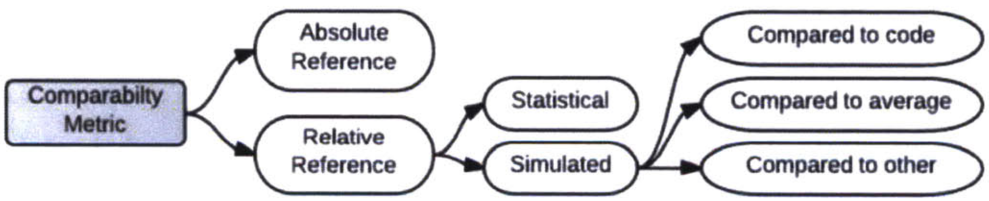


Figure 29: Comparability Metric Options

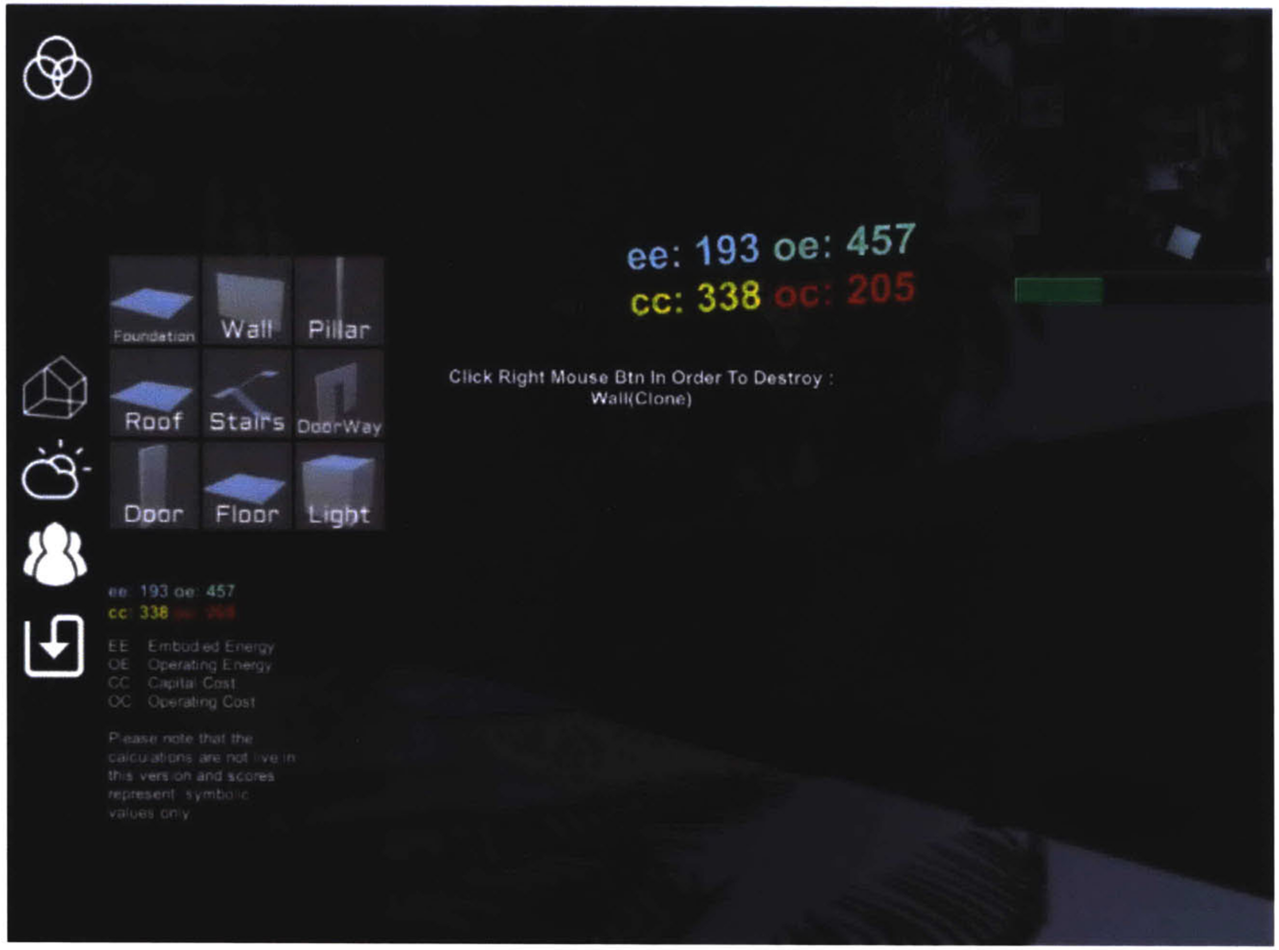


Figure 30 : Analytics: Raw scores can be found as labels above building or in menu, while green benchmarking bar shows percentage improvement from baseline

[CHAPTER 5: TESTING & EVALUATION]

The focus of the thesis was to propose a new conceptual framework, more so than to discover user preferences on interface design, therefore a paper prototype would be ineffective in conveying interaction and experience. To assess the viability, it was important to develop a prototype to test among design professionals in Qatar. Despite that this version was lacking in full functionality, users reported that it was sufficient to demonstrate potential usability. In addition, users provided feedback on existing methods and tools for early design, as well as their preferred features for future versions.

[5.1 USER SURVEYS]

A guided survey of twenty questions was structured to get a quick impression on the ways in which local construction professionals are currently developing designs as well as feedback on the tool prototype. A sample of 6 potential users from Qatar were contacted to share their thoughts and experiences. The sample consisted mostly of architects, and included a civil engineer and a real estate developer, all working in firms ranging between 50 and 400 employees. A small focused sample provides an initial gauge of desirability, and Figure 12 shows how 5 users is adequate to be able to identify about 85% of all usability problems[144]. In accordance with institution regulations regarding human subject testing, the interviewer passed COUHES training and sought user permission for the research, ensuring the survey met ethical and legal guideline. To maintain a low risk testing protocol, no identifiable data was collected on the respondents, nor were discussions recorded. Results to the survey can be found in the appendix.

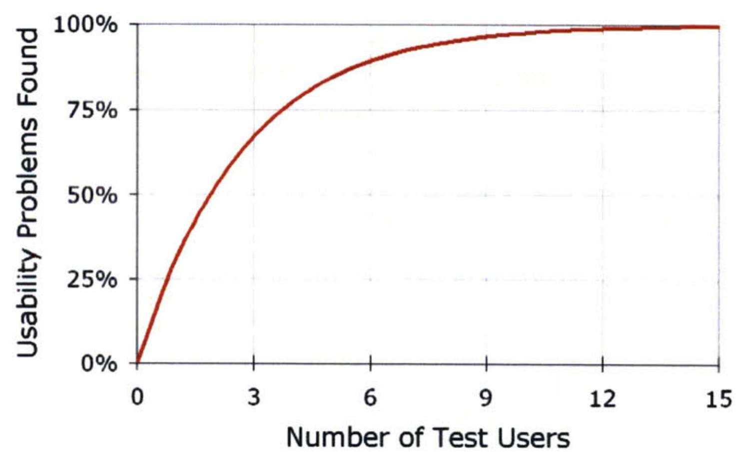


Figure 31: 85% of usability issues can be found from sample of 5
Source: Neilson, 2000

[5.1.1 CURRENT PRACTICE]

For architects, hand drawing is the main way in which they explore design solutions at the start of the project. Physical models were cited as desirable but too time consuming. Digital models have been gaining in popularity for conceptual design, particularly with the emergence of parametric design with plug-ins like Grasshopper for Rhino and Dynamo for Revit. These generative design platforms offer programming functions to navigate variances in solutions to predefined goals and constraints, limited only by what the designer can define mathematically and algorithmically and as such are mostly used as form finding tools, a process termed "digital morphogenesis" by Kolaravec.[145] Though appealing for exploration of problem's design space and producing unexpected results, it causes in disconnect between the ability to create geometrically intricate designs and developing functional proposals. While these tools have the capability to assess performance, and can be integrated with sophisticated simulation software like EnergyPlus for design optimization problems, these are complex to set up in unintuitive interfaces, and require additional user proficiency in a programming language. Again, this means that analytical tasks are not assumed until a design is developed. Interestingly, the engineer and developer considered cost as a driver of conceptual design, in addition to two architects, accounting for over half the sample, while none selected energy analysis. Generally, there is every effort to establish realistic budgets with the client early in the project, approximated by a total cost per square meter based on historical projects and prices. The engineer believes that the search for the most efficient structure will usually be the most economical, and so cost is a reflection of good design. The others have indicated that this is because projects are largely initiated as investments, cost becomes highest priority for the client, weighing most decisions by economic value. Operating costs are rarely requested or considered.

Passive strategies are used to some extent in every project, the most common being insulation and shading. Users agreed these are favored as non-design dependent features, and could be specified even within the detailed design. Building massing and organization of spaces with consideration of siting and orientation could often be dismissed. Other external factors can hinder materialization of these strategies, one architect commented as an example that specified insulation is substituted during construction procurement by the contractor and client to save material costs. This again reflects the inconsistency in priorities between developers and occupiers. Concrete as the most common building material has naturally high thermal mass, but prefabricated hollow blocks lack the mass required from 100-200mm thick walls, and benefits from an insulating layer.

There was a mix of responses for overall demand reduction strategies. Two of the respondents were LEED certified professionals who pursued sustainable design through QSAS certification of projects. Demand from various clients and new government regulations following the launch of QSAS in 2009, enforcing the use of Green Building Code in the Qatar Construction Standards for all new projects, has led to surge in demand for energy aware professionals. Many commented these regulations have been restrictive and expensive, and are not a reliable standard for energy reduction. The users showed a lack of consensus on adequate digital tools for conceptual design, while some didn't use any at all, others found some Sketchup, AutoCAD and Rhino useful for formalizing ideas. Generally, the process remains in 2D, from sketch to renders and plans, until a detailed model is produced in the design development phase. The most common criticisms for existing tools was that there was insufficient information for input at this stage, the time investment required and the lack of design freedom. Users commented that the analysis usually takes places at the latter end of the design process once a design has been selected for development and rarely occurs more than once during a project. All users revealed that either an in house or external energy consultant was responsible for developing an assessment. All users indicated desirability for a tool that would introduce cost and energy modeling to the start of the design process.

[5.1.2 PROTOTYPE TESTING]

The prototype received positive feedback for the conceptual framework, with many highlighting that the interactive experience of the environment helped them to be more conscious of the context for which their design is proposed. Many suggested its value for educational purposes, for example when introducing students to architectural design, in contrast to existing studio and CAD environments that disconnect from natural processes. Saving time was a key benefit; usually due to client pressures on time, models as a form of exploration and analysis are not frequently employed for projects. All users logged times under 15 minutes to develop an initial design proposal from when they launched the tool with no prior instruction. Additionally, users confirmed that tool provided rational scientific basis for conceptual design, making it useful for performance driven designs.

The proposed interface is primitive in its functionality and appearance relative to the potential of the engine. Due to time constraints, I was unable to develop the interface beyond programming key functional integrations and could not justify asking interviewees for additional interface and debugging feedback. For a higher level understanding of preferences, all users were happy to use the tool as a desktop application, though many saw potential for a web platform particularly if used for remote access or collaboration. For the interface, two proposals were offered to assess preferences on the level of static GUI information presented, shown in Figure 32. The first overlaid static icons to the top and bottom bars of the GUI containing direct access to the components and preferences options while the preferred was similar to the prototype format with expanding menus. Though the full screen environment was received enthusiastically, they said visual distinction between the model

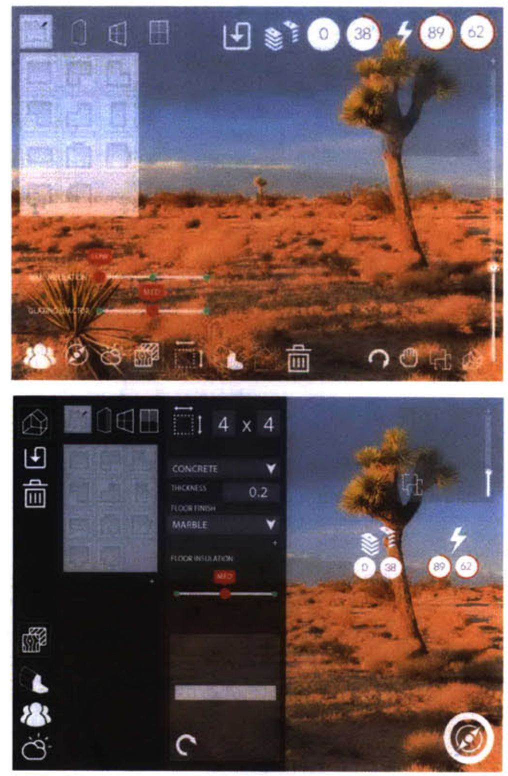


Figure 32: Interface and Menu structure preferences

environment and input options. This also meant a clear workspace that could switch between design mode and visualization mode instantaneously. The hierarchy of windows was considered more effective at controlling the level of detail and complexity that a user works with. Many commented on the potential of the platform to support a high level of details, graphics and resolution, allowing designers to quickly produce renderings and videos with low effort within the same tool.

[IMPROVEMENTS FOR FUTURE VERSIONS]

Main issues that users identified related to the virtual environment and data visualization. Improved. Improvements to representation and graphics are necessary to fully exploit the game engine platform, though both of these warrant additional research on how best to convey contextual and measured data. With a dynamic sun cycle visualized, it would be ideal to have daylighting metrics and glare analysis integrated. Interaction and controls could also benefit from refinements: for example, one user suggested more flexibility in navigation, which would allow them to maneuver between cameras to switch from a multitude of views and perspectives. Further, it would be feasible to have user placed cameras and 'teleportation' points that could allow quick access to chosen parts of a model.

With only basic functions live, there is obviously a multitude of areas requiring further research and attention for a second version. Developing a comprehensive database of components and materials to be utilized in programming the tool to extract data from the building model for calculations is the first challenge. Each of the components must contain accurate material properties data that would update according to changes in settings. Information visualization for these data analytics will be crucial to ensuring interpretation and understanding of results. Choosing the appropriate type of feedback for these actions is also important, for the user to visualize and understand the implications of decisions. The database is currently limited in its options and settings and should have more variance of components and conditions to experiment. Users placed a runtime building editor as higher priority than a community repository of elements, suggesting further customizability of components is desirable. Interoperability between software was also important to allow a more seamless experience to also feed customized components into the database and later export the 3D model for further refinement and development.

[CHAPTER 6: CONCLUSIONS]

Passive strategies are relatively inexpensive, low carbon measures that respond to the changing environment, proven to improve thermal comfort and reduce energy consumption. The aspiration of this thesis was to propose a new tool that could support a designer's exploratory form finding process in an easy to use interface with approximated yet rational analysis on energy and cost performance of design proposals, to assist with conceptual phase decision. A prototype of the way this could manifest was developed by integrating a gaming engine with recognized industry methods for estimating, to promote a user centric experience for the design tool, with the intention of lowering barriers to wider adoption. In this final chapter, I will summarize the successes and limitations of the proposed tool in meeting these objectives, along with key findings from potential users. This will be followed by a series of suggestions for future work and opportunities for further research. Finally, some concluding remarks will address wider issues of energy related to culture and environment to advocate for imperative action in holistic demand management.

[6.1 SUCCESSES & IMPLICATIONS]

One of the key limitations to users implementing passive strategies, is that energy analysis has become increasingly complex and therefore relegated to the latter end of the design process to be conducted by trained specialists. The goal of this research was to accommodate interdisciplinary design processes through divergent thinking and rational analysis in an easy to use interface. Through prototype testing, potential users confirmed market desirability for such a tool and later validated the success of the tool to assist with early design decision making, shifting the exploration of energy efficiency to the start of the design process.

This indicated potential for a reconsidered workflow as well as initiating interdisciplinary discourse amongst a wider audience. The simplification and understanding of complex relationships is necessary if they are to penetrate societal norms. Users were optimistic on potential uses for educational purposes, as well as accessibility for stakeholders such as developers, homeowners and policy makers. Increased communication and collaboration can redefine traditional roles, introducing transparency.

Users reported that they appreciated the ability to rapidly and simultaneously consider design energy and cost, to understand dependencies and assess optimal solutions for each project and considered it an aid to the creative process. The communication and understanding of how such relationships arise has the potential to influence building regulations and policy, for example, similar to the new regulations on thermal insulation, if it can be demonstrated that thermal bridging consistently offered a reduction in heat transfer, authorities may mandate all new constructions to comply with standards for sealing joints and points of loss.

Testing largely found that value propositions of the conceptual framework were valid and sufficient to differentiate from existing market tools. Initiated many discussions and differing interest shows flexibility in use and huge potential for a fully featured application.

[6.2 LIMITATIONS]

All software is limited by how we can describe our intentions and how they are computationally interpreted. Natural ventilation and evaporative cooling are key passive cooling techniques that have been excluded from the scope due to the difficulty in measuring their effectiveness. Natural ventilation is an effective cooling strategy, but is difficult to assess, not least because Passivhaus advocates for air tight envelopes. Passivhaus was chosen as an adequate standard that uses a simple spreadsheet to measure energy performance. Though it claims to be applicable for any climate, it was developed for a heating dominated region and may not support alternative cooling strategies.

Other software to drive simulations should be considered, such as EnergyPlus that would offer greater accuracy, but in reality, the abstraction of Passivhaus lends itself to the vague inputs and assumptions of PATED, where the intention is not to be predictive but rather indicative and comparative. The sacrifice of accuracy in favor of usability, is accepted for early designs. Also, the Passivhaus standard is more suited skin dominated buildings: while appropriate for residential homes, there will be a scale at which heat loss and gain through the envelope will have a much less effect on consumption relative to the selection of mechanical systems. Non-component features can still be provided as options to users to emphasize implications of decisions. This could mean that the user could visualize the impact of equipment choice or improving thermal bridging.

The tool clearly has a greater impact the earlier it is used in the design process. This applies not only to software but to any kind of tool. Each tool, analog or digital, has a "range of operation" that allows the user to perform certain actions, thus defining the repertoire of design solutions according to its "bias".[146] The building system thus is limited by components and their conditions, restricted by rules that dictate joint details, in turn limiting the geometries can be produced, making it predictable to a certain degree. A runtime building editor could help to rectify this by allowing further customization of the prefabricated elements, or perhaps there is a more appropriate scale of unit for building, such as a brick. Visualization of the environment, components and information will require extensive research to develop representative and appealing interactions.

[6.3 OPPORTUNITIES FOR FURTHER RESEARCH]

The wider literature shows that research & studies on passive cooling strategies for the hyper arid has not been granted the same level of attention as passive heating for example. The climate data and geo specific inputs for the model are both minimal and modifiable, making the tool replicable for other contexts. Still unresolved, is the question of how can adapt the tool to become more culture specific? A primary interest of the tool is to support a system through which users can learn from tested designs and feedback this knowledge into the platform to share with others. The idea is to use the platform as a repository of local building knowledge and to explore and adapt solutions from similar conditions to develop an architectural language derived from the region. The tool is aimed at architects to take advantage of expanding and adding to the knowledge base, to be less prescriptive, but the hope is that this platform can then be disseminated for public use.

Exploring emerging technologies in other disciplines can open new avenues for architectural tools: crosspollination can enrich experiences and interactions to encourage symbiotic relationships between human and computer for design. Feedback seems to be leaning towards embracing the video game platform further. Habraken and Gross[147] stated, "design is a social activity that takes place among people who negotiate." A design game should encourage social interaction to promote learning and communication. The prototype does not yet support multiple users, though this is certainly feasible, allowing a higher level collaboration than with existing tools. Multi user support and collaboration will be key to develop a community around interdisciplinary knowledge sharing. In addition, this provides a remote workspace, through which collaborators can explore and discuss solutions for distant teams or sites. This allows participatory design with an alternative model that moves beyond the dominant practices of advocacy planning, instead advocating the "democratization" of design through immediate user empowerment and participation."[148]

As an educational tool it may necessitate implicit and explicit goals for challenge, motivation and competition. There are two main audiences for an educational design tool: professionals working within or with the construction industry and the wider public, each warranting a tailored interface. Social education or architectural education require guidance towards improvements and place greater importance on engagement and visualizing model performance and feedback. For engagement with the wider public, how can the nature of play through video games licit the cultural shift. For example, what role does social media, inducing consistent engagement through incentives by awarding rewards or badges as they meet objectives and goals, or as they compete with others.

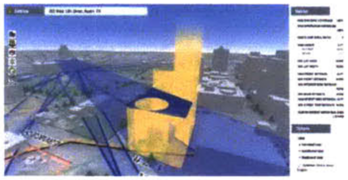
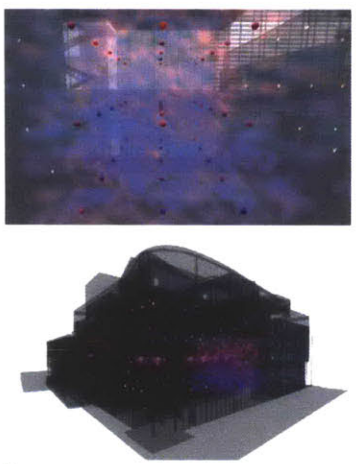


Figure 33 Flux.io Metro project
Source: Dideck, 2015

Figure 34: Construction Simulator 2015
Source: https://www.youtube.com/watch?v=uiW_eluluO0



Source: http://doppellab.media.mit.edu/

Interoperability was rated as desirable feature as continual frustrations were voiced over the difficulty of transposition between disciplines and tools, impeding workflows. Interoperability between the Unreal game engine and Rhino has been demonstrated by the same team who have developed the Quartz database (FLUX.IO). Their expertise seems to lie in information consolidation, as another initiative 'Metro' could have interesting implications for PATED. Working on geo-specific site while visually interpreting building codes and land use regulations for a city in Texas, this tool provides visual feedback of the regulatory constraints for every site, effectively defining a buildable envelope, see Figure 33. Future interoperability will allow integration of a wider range of analysis tools. This begs the question of how can generative design or structural analysis add further value to developing conceptual designs. construction methodologies. How could this be adapted into a tool by which contractors can utilize to improve designs, knowledge, training and construction? This potentially adds many layers of detail and greater stakeholder involvement. For example, to assess how active solar systems can be integrated into a building's design and systems.

Game engines have been used to visualize networks of sensors, such as the DoppelLab project from the Responsive Environments Lab at MIT.[149] This provides an immersive, cross-reality virtual environment that serves as an active repository of the multimodal sensor data produced by a building and its inhabitants, transforming architectural models into browsing environments for real-time sensor data visualizations, see Figure 34. PATED could potentially be linked to urban models that reflected actual measured real-time data of existing buildings for comparison to proposed designs. New frontiers of virtual reality are incrementally being adopted for visualization purposes. Radford[150] forecasts that the next generation of CAD will embrace virtual reality to "have the design in there, in a 3D world amongst his or her design, not looking from the outside through a computer screen. Making designs will be like making objects, with the workshop inhabited by the designer." The immersive nature of virtual reality will offer new levels of understanding and testing spaces at the corresponding scale.

[6.4 RECOMMENDATIONS FOR HOLISTIC ACTION]

Ultimately, the journey towards an energy conscious culture can only be successful if these is holistic action; tools are only useful insofar their use in conjunction with other measures. Replacing fossil fuels with renewables, eliminating flaring and improving water efficiency harbor huge potential for demand reduction in Qatar, each one with their own challenges. For example, despite being one of the world's sunniest cities, solar power has low rates of efficiency from excessive heat and dust. Further, adoption of renewables at the homeowner scale would require incentives, or infrastructure at the very least to sell excess capacity to the grid. Support and directives from the government is necessary in this context to protect occupiers from developer decisions motivated by capital cost saving. Meanwhile, carbon pricing and a rating system based on measured performance can reduce risk of greenwashing. While passive strategies target the building design, it should still be noted that the greatest gains in building energy reduction are from efficiency of mechanical systems.

Though we may be unable to escape the dependence on artificially cooled spaces, an integrated approach is critical to improving the environmental performance of our buildings. While passive strategies offer the first step, we must also reconsider lifecycle consequences of active systems, energy sources and occupant behavior to successfully minimize impact. Innovate forms of social education will be necessary to continue driving down consumption and motivate a cultural shift. This thesis hopes to provide a critical dialogue of the efficiency of passive strategies embedded within the envelope along with their economic implications at a resource restricted stage in the design process where it has the potential to maximize impact. In promoting continuous negotiation between different configurations, such an instrument offers ease of adoption through insight into compromises of key constraints for a variety of stakeholders involved in the early stages of the design process.

[APPENDIX]

Consent to participate:

You have been asked to participate in a research study conducted by Tanya Ismail from the Department of Architecture at the Massachusetts Institute of Technology (MIT). The results of this study will be included in the Masters thesis: Passive Architecture Tool for Exploratory Design. You were selected as a possible participant in this study because of your experience as a design professional in Qatar. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

- This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time or for any reason. I expect that the interview will take approximately 30 minutes.
- You will notbe compensated for this interview.
- Unless you give us permission to quote you in any publications that may result from this research, the information you tell us will be confidential.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

6 out of 6 people answered this question

1	Yes	6 / **100%**
2	No	0 / **0%**

What tools/methods do you use for design exploration during conceptual design?

6 out of 6 people answered this question

1	Hand Drawings	5 / **83%**
2	Cost estimating	3 / **50%**
3	Digital models	3 / **50%**
4	Physical Models	3 / **50%**
5	Energy analysis	0 / **0%**
6	Other	0 / **0%**

6 out of 6 people answered this question

1	Design Development Phase	6 / **100%**
2	Conceptual Design Phase	1 / **17%**
3	Construction Drawings Phase	0 / **0%**
4	Other	0 / **0%**

What are the most common passive cooling strategies implemented in projects?

6 out of 6 people answered this question

1	Insulation	6 / **100%**
2	Shading	5 / **83%**
3	Natural Ventilation	1 / **17%**
4	Siting / Orientation	1 / **17%**
5	Other	0 / **0%**
6	Thermal Mass	0 / **0%**

Which are the most common energy conscious strategies implemented in projects?

6 out of 6 people answered this question

1	High Performance Materials	5 / **83%**
2	Heat gain control to reduce air conditioning demand	4 / **67%**
3	Green building certification e.g. LEED / QSAS	2 / **33%**
4	Natural daylighting to reduce electrical demand	2 / **33%**
5	Renewable Energy Generation e.g. Solar panels	2 / **33%**
6	Other	0 / **0%**

Limitations of currently available digital tools for conceptual design evaluation?

6 out of 6 people answered this question

1	Insufficient information available at this stage of the design process	6 / **100%**
2	Time Consuming	5 / **83%**
3	Expensive	3 / **50%**
4	Lack of design freedom	3 / **50%**
5	Requires training	1 / **17%**
6	Inaccurate	0 / **0%**
7	Other	0 / **0%**

Do you use any specific digital design tools during the conceptual design phase?

6 out of 6 people answered this question

1	Rhino / Grasshopper	3 / **50%**
2	SketchUp	3 / **50%**
3	AutoCAD / Revit	2 / **33%**
4	None	1 / **17%**
5	DesignAdvisor	0 / **0%**
6	DesignBuilder	0 / **0%**
7	Graphisoft ArchiCAD	0 / **0%**
8	Other	0 / **0%**
9	Rapiere	0 / **0%**

Do you think a tool that provides environmental and cost benefit analysis on design decisions at the start of the design process would be useful?

6 out of 6 people answered this question

1	Yes	6 / **100%**
2	No	0 / **0%**

Did you find the component based building system able to accommodate design exploration and quick production of a variety of architectural proposals for evaluation?

6 out of 6 people answered this question

1	Yes	6 / **100%**
2	No	0 / **0%**

Do you think the tool will be useful for the following?

6 out of 6 people answered this question

1	Developing ideas quickly	5 / **83%**
2	Performance based conceptual design	5 / **83%**
3	Evaluating passive strategies	3 / **50%**
4	Communication	1 / **17%**
5	Other	0 / **0%**

Which aspects of the user interface did you identify issues with?

6 out of 6 people answered this question

1	Data visualization	4 / **67%**
2	Virtual environment	4 / **67%**
3	Preset Components	3 / **50%**
4	Changing settings of components	2 / **33%**
5	Conditions for building	1 / **17%**
6	Help / Documentation	1 / **17%**
7	Navigation	1 / **17%**
8	Menus or icons	0 / **0%**
9	Other	0 / **0%**

Which of the following do you agree would be value proposition for the proposed tool?

6 out of 6 people answered this question

1	Rational scientific basis for conceptual design	5 / **83%**
2	Saves time	5 / **83%**
3	Educative	3 / **50%**
4	Enhances collaboration	2 / **33%**
5	Minimizes rework	1 / **17%**

What kind of platform would you be interested to use this on?

6 out of 6 people answered this question

1	Desktop	6 / **100%**
2	Web	4 / **67%**
3	Mobile	0 / **0%**
4	Other	0 / **0%**

For future development of the tool, which of these features do you consider to be important?

6 out of 6 people answered this question

1	Export models to other CAD software	5 / **83%**
2	In game building component builder/editor	5 / **83%**
3	Daylighting analysis	3 / **50%**
4	Multiple users can edit: collaborative capabilities	3 / **50%**
5	Community driven repository of components	2 / **33%**
6	Geolocated real world data & positioning	1 / **17%**
7	Local urban environment modeled	0 / **0%**
8	Other	0 / **0%**

Which of these interfaces do you prefer?

6 out of 6 people answered this question

 1	Expanding menus	6 / **100%**
 2	Static Icons	0 / **0%**

Do you think the tool will encourage designers to implement energy sensitive strategies into the conceptual design?

6 out of 6 people answered this question

1	Yes	6 / **100%**
2	No	0 / **0%**

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