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SCHREYER HONORS COLLEGE

THE SCHOOL OF ENGINEERING DESIGN, TECHNOLOGY, AND PROFESSIONAL PROGRAMS

DECISION MAKING WITHIN THE BUILT ENVIRONMENT AS A STRATEGY FOR MITIGATING THE RISK OF VECTOR-BORNE DISEASES SUCH AS MALARIA

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ABSTRACT

Although significant efforts have been made to combat the spread of vector-borne diseases (VBDs), they still account for more than 17% of all infectious diseases. According to the World Health Organization (WHO), there were 216 million estimated cases in 2016, which is a 9.3% decrease from the estimated cases reported one decade earlier. It is known that the built environment, through features such as openings, can propagate the spread of malaria. There have been some significant efforts directed at addressing this risk. This notwithstanding, there are some knowledge gaps that have resulted in a missed opportunity for synergistically tackling the problem of vectors through leveraging design decisions made by built environment professionals. This work assesses the extent to which design decisions in the built environment can have a positive impact on the efforts directed at mitigating the risk of malaria based on selected cases from East Africa. The research was conducted in two phases. During the first phase, secondary data derived from relevant urban health journals as well as repositories curated by leading health agencies such as WHO were synthesized and analyzed using a web of causation approach. The outcome of the analysis is a schema of primary and secondary source (risk) factors. The use of the web of causation approach revealed the existing factor-to-factor interactions that could have a reinforcing effect. This information was used to identify the critical linkages and interdependencies across different factors. The outcome of the analysis was mapped against risk factors that can be linked to decisions made during the six primary phases of the construction life cycle: preliminary phase, conceptual design, detailed design, construction, facilities management, and end of life/disuse. The results from the first phase of the research were validated during the second phase through a survey of 34 East African–based built environment professionals. The findings of the research have established that 1) there is, in fact, a built environment–related opportunity that can be leveraged to advance the impact of malaria mitigation effort; 2) cross-disciplinary synergies are critical to managing the interdependencies and complexity of malaria risk factors that have a reinforcing effect; and 3) a knowledge-management framework that serves as a decision support tool would be valuable for sharing data under a push-and-pull mechanism, in which data shared in real time can address the timeliness of mitigating the spread of malaria at the earliest stages for the greatest impact. Based on the findings, a conceptual architecture for a decision support framework has been proposed. This will be developed into a knowledge-management platform in subsequent efforts.

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Chapter 1 Introduction

1.1 Contextual Background

The overarching goal for this research is to assess the extent to which design decisions in the built environment can have a positive impact on the efforts directed at mitigating the risk of malaria, based on selected cases from East Africa. In 2016, there were an estimated 216 million cases of malaria in 91 countries (World Health Organization), which surpasses the prevalence of other tropical or neglected diseases such as HIV/AIDS and dengue fever (see Table 1).

Table 1: Infectious Disease Cases
(WHO 2016)

Tropical Disease	Number of People Infected in 2016
Malaria	**216 million**
HIV/AIDS	36.7 million*
Tuberculosis	10.4 million
Dengue	3.2 million*
Leprosy	200,000
Ebola	28,600

Around 445,000 deaths occurred in 2016 as a result of this disease . The World Health Organization (WHO) Global Malaria Program, through close collaboration with governments of endemic countries and regulatory authorities, has factored in safety and surveillance, drug efficacy, and financial burden in their efforts directed at accelerating progress towards malaria elimination (Global Technical Strategy for Malaria, 2015). According to the WHO, there was a 9.3 % decrease in the number of reported cases between 2006 and 2016. The Global Fund, one of the largest malaria prevention organizations, disbursed over USD 9.1 billion in 2016, a 90% increase from the funding that was provided a decade earlier (Global Fund, 2017). The opposing trends of decreasing estimated cases per year and increasing costs for malaria prevention (see Figure 1) underscore the need for new strategies for mitigating of the propagation of malaria.

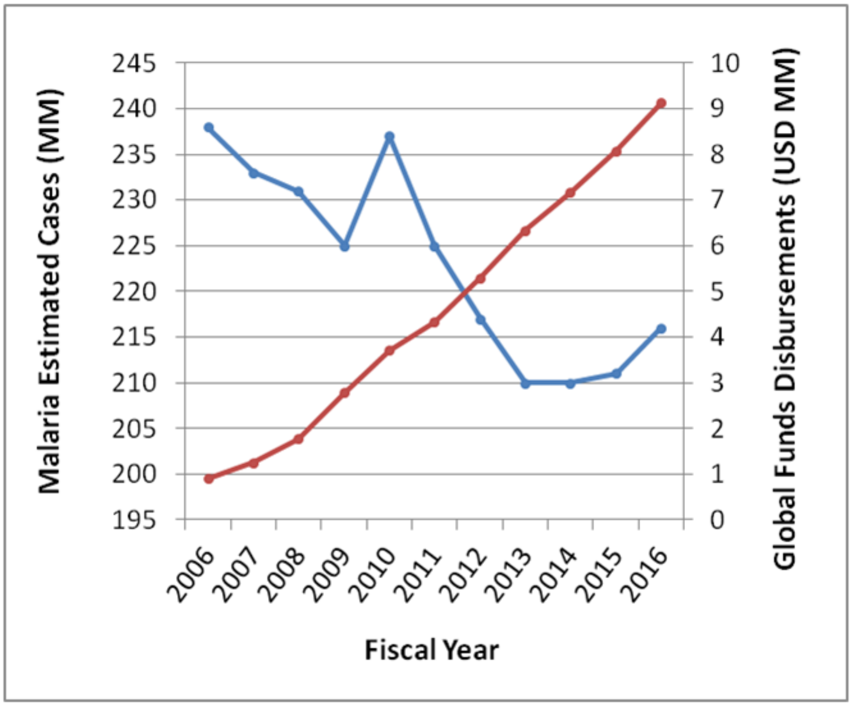

Figure 1: Relationship between Global Spending Trends and Estimated Cases of Malaria (WHO World Malaria Report, 2010 and 2017; Global Fund Malaria Financials, 2017)

Regions of South America, South and South-east Asia, and Sub-Saharan Africa had a stable prevalence of malaria in 2009, as shown in Figure 2. Regions closer to the equator had higher prevalence, and regions farther away were either formerly malarious or never malarious. Seven years later, the larger number of deaths from malaria was concentrated in sub-Saharan Africa, as shown in Figure 3. Although the number of cases may have decreased in some developed nations, malaria is still severe in countries that are in low and emerging economies. Currently, international agencies such as the USAID, WHO, Wellcome Trust, Roll Back Malaria Group, and the Presidential Malaria Initiative (PMI) have invested millions of dollars to prevent and decrease the spread of malaria in sub-Saharan Africa. Professionals in medicine, entomology, epidemiology, the built environment, and public health policy have contributed towards the development of international programs and scientific research to address the crisis.

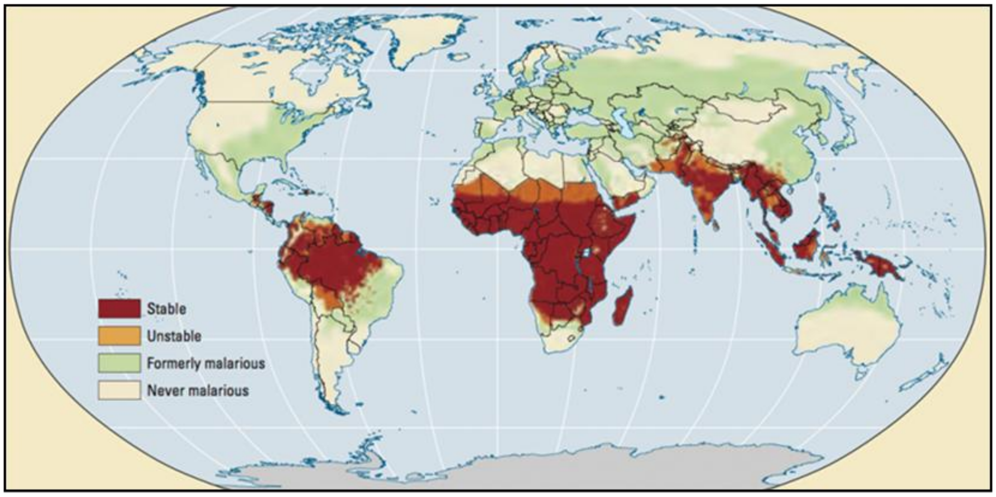

Figure 2: Severity of Malaria Prevalence in 2009
(World Bank, 2016)

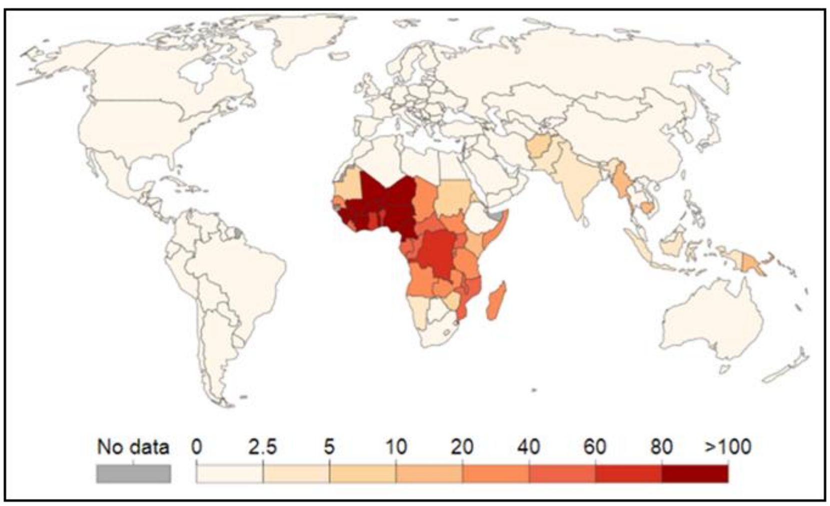

Figure 3: Malaria Death Rates per 100,000
(World Bank, 2016)

1.2 Theoretical Background

It is known that effective design and construction of buildings and other assets can help combat the spread of vector-borne diseases (Tusting et al., 2015). This is evident from the malaria intervention program that was implemented during the construction of the Panama Canal. According to the Centers for Disease Control and Prevention (CDC), built environment–related strategies such as pool drainage near homes, bush cutting, and building screening resulted in a decrease in the percentage of the workforce hospitalized because of malaria from 9.6 % to 1.6 % between 1905 and 1909 (CDC, 2016).

There are several interventions that have leveraged lessons learned from the Panama Canal project. Examples include modification of building envelopes through reducing the size and/or number of openings such as windows (Ogoma et al., 2009). These reduce the ease with which mosquitoes gain access to a building. Other efforts focus on material selection given the that there is a positive correlation between the use of traditional building materials and techniques, and the prevalence of malaria (Tusting et al., 2015). There are also some examples of intervention programs that focus on management of the existing drainage systems (Le Prince, 1915), which provide the ideal conditions for breeding the malaria-causing mosquito. Although these types of intervention programs have resulted in some positive effects with respect to malaria prevention, the author contends that their impact is limited because they are largely driven from a public health perspective.

A comprehensive review of published literature did not reveal any evidence of built environment professionals responsible for critical decision-making responsibilities featuring prominently in the existing malaria intervention efforts (see examples in Table 2). It appears that the overlap between the public health champions of housing modification for the control of malaria and the built environment stops at the level of construction trades.

Table 2: Categorization of Literature Reviewed

	Research Focus	
Motivation	**Outcomes assessment and impact evaluation**	**Spatial Analysis of the spread of Malaria**
Promoting Public Health from a Global Perspective	Mgone, 2010; Marshall et al., 2010; Atkinson, 2011; Wang et al., 2006; Marshall and De Silva, 2012; Qiuyin, 2012.	Hausmann-Muela, Susanna and Julian Eckl, 2015; Ocampo et al., 2013; Tatem, 2014
The link between Climate Change and the occurrence of Malaria	Reiter, 2008; Klinkenberg et al., 2008; Hay et al., 2002; Adefemi et al., 2015.	Zhou et al., 2007; Lindblade, 2000; Tonnang, 2010; Edlund et al., 2012
Opportunities for Built Environment-related mitigation	Lindsay et al., 2002; Menger et al., 2014; Gamage-Mendis, 1991; Lindsay SW et al., 2003, Harrysone et al., 2009; Tusting et al., 2015; Tusting et al., 2016; Marshall and De Silva, 2012	Marshall and De Silva, 2012; Waite, et al 2016.

There is evidence of cross-disciplinary collaboration in efforts focusing on investigating: 1) clinician-versus-patient perception of malaria diagnosis (Chandler et al., 2008); 2) impact of different public health models on policymaker and developer decisions (Nunes et al., 2013); 3) the role of bioinformatics modeling techniques (Suhanic, 2009); 4) the role that social entrepreneur and community sector organizations can play in improving both the diagnosis of malaria and the implementation of interventions (Allen et al., 2010); and 4) the development of strategic partnerships between the public and private sectors (Njau et al., 2009). There have been some positive outcomes arising from such efforts. However, there is still a need for more work to be done to fully leverage the existing opportunity to increase the impact of mitigating the risk of malaria through focusing on built environment-related factors. According to a meta-analysis and systematic assessment conducted by Tusting et al. (2015), housing, in particular, presents as a significant risk factor for malaria. There is, therefore, a critical need to generate actionable insights on both the magnitude and complexity of this problem.

The nature of the problem involves a public health aspect, built environment aspect, and a bridge between both fields. In particular, climate change is expected to create environmental conditions that have adverse effects on the incidence of VBDs (see Figure 4). For example, abiotic factors such as wind pattern, precipitation pattern, and relative humidity can influence vector migration, seasonal population density, and genetic composition of vector populations (Climate Nexus, 2016).

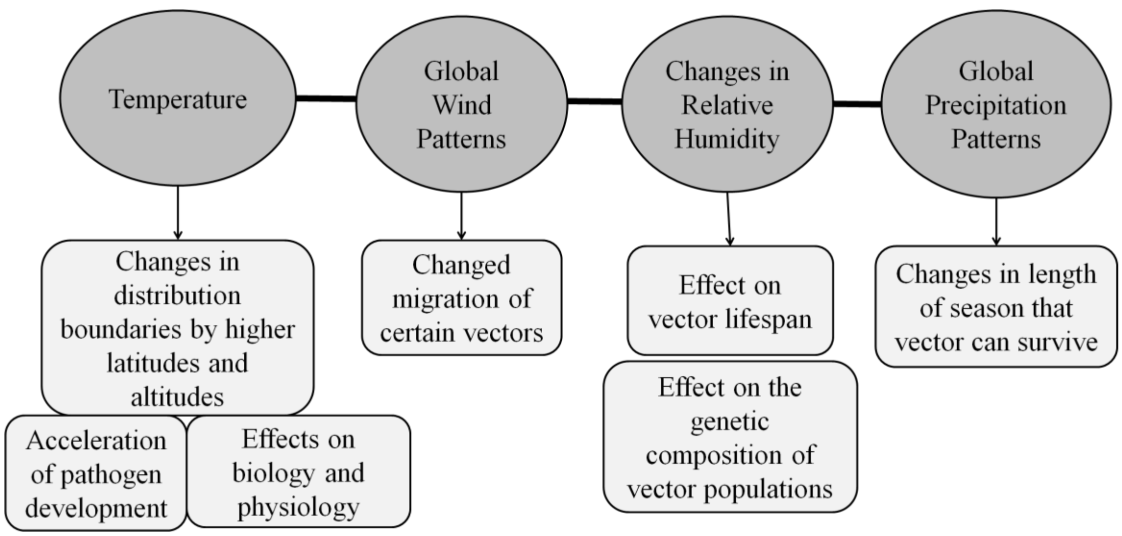

Figure 4: Direct Effects of Climate Change on Disease Vectors
Adapted from (Columbia Earth Institute Climate Nexus, 2015)

Themes that may share an indirect link towards built environment health may also factor into increased risk of malaria propagation. Such examples include social determinants of health, mental health, government advocacy, safety practices, urban planning, public–private partnerships, and healthcare access. For instance, one socio-cultural factor that influences the prevalence of malaria, particularly in children, is the hierarchical structure of families among communities with social stratification in parts of Nigeria (Adefemi et al., 2015). Children under five years of age have a greater need than adults for nutritiously balanced meals because they do not have a strong built-in immunity. In areas where food is scarce, fathers hold the right to the best meal, and children are often left with food that does not permit adequate growth and development for their age (Adefemi et al., 2015). Additionally, some barriers to effective intervention strategies that involve a cross-disciplinary consideration include access to public health information and level of spirituality. Some communities may have limited access to information in print or electronic media. Adefemi et al. (2015) noted that the presence of malaria under the compass of ill-health is often related to the presence of demons or evil spirits, which require herbal and spiritual remedies or behavioral changes.

1.3 The Built Environment Opportunity

Mitigating the risk of VBDs should be one of the design objectives for buildings in countries with a high incidence of malaria. An existing built environment–driven, healthy building movement that can provide the starting point for the proposed approach (Dodge Data and Analytics, 2016). Common issues explored in such initiatives include indoor pollutants, particularly those that arise from the use of toxic chemicals in paint and other building finishes (SmartMarket Report, 2016). Some efforts focus on investigating the risk of respiratory illness that can be linked to moisture-related problems such as mold. It is worth noting that the existing healthy building initiatives are championed by stakeholders in western countries. The focus, therefore, is largely on diseases and health problems that occur in countries such as the U.S., Canada, the U.K., and Australia that do not have a big problem with respect to VBDs. There are also some significant opportunities for education with respect to the different types of diseases that have a built environment-related contributing factor. In its comprehensive study of the interface between buildings and health, Dodge Analytics (2016) specifically underscored the need for more research and data on how to improve building health impacts and more public awareness campaigns on the significance of this interface.

There is a critical need to increase awareness of the different ways through which the main activities undertaken throughout the life cycle of a construction project can propagate the spread of malaria. Design professionals are either directly responsible for or uniquely positioned to influence decision making in each of these phases. The missed opportunities for them to contribute to the risk of malaria is outlined below:

1) *Preliminary Phase:* Selection of a site near an open surface water body may increase the number of breeding sites for the malaria vector.
2) *Conceptual Design:* The placement and size of openings as well as the orientation of the building envelopes affects the vector accessibility both into and out of the building.
3) *Detailed Design:* Certain types of material on housing features such as mud walls, thatched roofs, and earth, sand, dung, and stone flooring increase vector attraction into the site (Wanzirah, 2015).
4) *Construction:* Excavation work results in opportunities for several pools of stagnant water to form — these pools are ideal breeding grounds for mosquitoes.
5) *Facilities Management:* Drains and ditches are common habitats for mosquitoes to breed (Mattah, 2017). Poorly installed pipes and drain blockage can lead to poor sanitation or reduced water flow. The accumulated stagnant water can become a favorable habitat.
6) *End of Life/Disuse:* Construction and demolition waste contributes to the environmental problem of landfills.

As shown in Figure 5, the largest window of opportunity for making an impact in an effective and efficient manner is during the conceptual design phase. There is a cost associated with changes made in subsequent phases that increases with time. Therefore, it is economically more beneficial to engage with professionals responsible for making critical design decisions during the formative stage of a project.

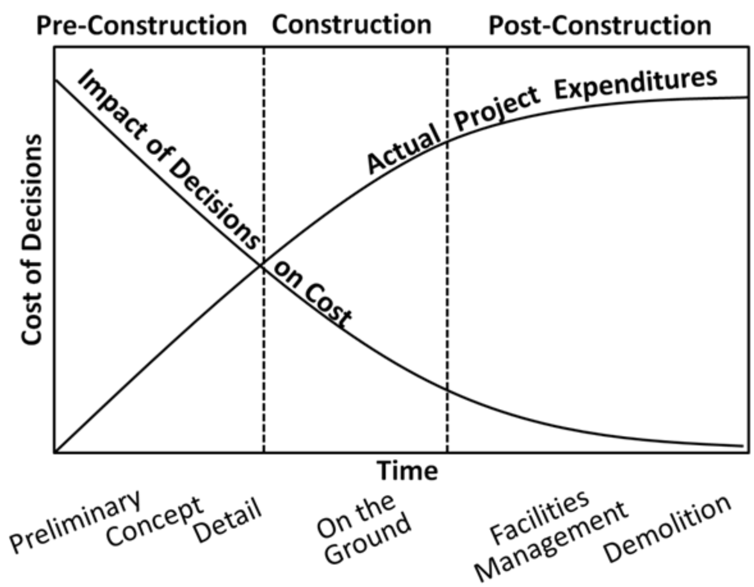

Figure 5: Cost-Benefit Curve — Early Decision Making in Construction Life Cycle
Adapted from (American Institute of Steel Construction, 2018)

There is a sense of urgency with respect to addressing the missed opportunity to leverage design decisions because of rapid urbanization rates. Half of humanity, 3.5 billion people, live in cities (United Nations, 2018), and it is estimated that by 2030, almost 60 percent of the global population will live in urban areas. According to UN population projections (2018), the parts of the world that are more adversely affected by malaria are going to experience the highest urbanization rates in the next several decades. In fact, there is a strong, positive correlation between increased urbanization and increased number of malaria infections (Donnelly et. al 2005). This is also apparent from the reported trends for malaria-prone regions in urban Kenya and Tanzania. Based on UN projections, Tanzania's population is expected to grow by 22% between 2014 and 2050, peaking at an estimated 68.5 million people (World Bank, 2018). During the same timeframe, Kenya's urbanized population is expected to grow by 19%, resulting in an estimated 42.6 million urban inhabitants. Rapid urbanization comes with increased construction activities because of growing demands for housing.

There is a growing urban slum population in both Kenya and Tanzania that is expected to increase seeing that the demand for housing is significantly much higher than the formal construction sector can supply. This is exemplified by the situation in Tanzania where the housing deficit is as high as 3 million (Kimani, 2017). There is a positive correlation between inadequate housing and the risk of malaria. Slum conditions such as poorly monitored land use and urban agricultural practices result in higher mosquito biting rates (Patz et al., 2004). Areas of low socioeconomic status, often at the periphery of cities, are more likely to have poor quality housing, unpaved roads, and reduced access to healthcare. These factors, combined with rapid urban expansion and ever-increasing city boundaries, result in increased transmission of malaria that town planners are unable to keep up with (De Silva and Marshall, 2012).

1.4 Guide to the Thesis

The introductory chapter of this thesis provided a review of the state of the art in the fight against malaria. It also presented the missed opportunity for the built environment to contribute to mitigation efforts. Chapter two describes the research methodology. The research was executed in two phases. A web of causation approach (Krieger, 1994) was used to perform a holistic identification of source factors and intervention methods. It also describes how an engineering design process, in which iteration and feedback enrich the outcome of each step of the analysis, was used to generate an assessment matrix. Chapter two also describes the validation of findings through a survey of built environment professionals in East Africa. The focus for chapter three is data presentation and analysis. In addition to outlining the mapping of source factors and intervention strategies against the matrix generated using the web of causation approach, this chapter also describes the statistical analysis performed on the responses to the survey questions. Chapter four uses the results of the analysis to enhance the understanding of the extent to which interdisciplinary risk factors contribute to the propagation of malaria. The final chapter also includes a discussion of the five major sub-themes of lessons learned from the research as well as recommendation for further work.

Chapter 2 Methodology

2.1 Overview

The research was conducted in two phases. During the first phase, secondary data derived from relevant urban health journals as well as repositories curated by leading health agencies such as WHO were synthesized. A web of causation approach was adopted to enable a holistic assessment of the identified factors. The outcome of the analysis was a schema of primary and secondary source (risk) factors. The use of the web of causation approach revealed the existing factor-to-factor interactions that could have a reinforcing effect. This information was used to identify the critical linkages and interdependencies across the different factors. The outcome of the analysis was mapped against risk factors that can be linked to decisions made during the six primary phases of the construction life cycle: preliminary phase, conceptual design, detailed design, construction, facilities management, and end of life/disuse. The results from the first phase of the research were validated during the second phase through a survey of 34 East African–based built environment professionals.

2.2 Phase One: Source Factor Characterization

Humanitarian engineering is linked to social science, so molding engineering design principles with public health–oriented data collection strategies requires a broad understanding of the variety of data available. A comprehensive review of existing literature was conducted using primary sources of information such as repositories managed by the WHO, World Bank, and Global Funds as well as publications from the WHO, CDC, the United Nations (UN), the National Institute of Health (NIH), Rollback Malaria Group, and Presidential Malaria Initiative. Additional insights were drawn from academic publications such as *The Malaria Journal*, *Tropical Medicine and International Health*, and *Environmental Health Perspectives*. In addition, during the formative stage of the research, the author conducted two semi-formal interviews with two East African-based professionals. The professionals interviewed were the Head of East and Southern Africa Operations and Capacity Building for Malaria Initiatives at Novartis, and a Quantity Surveyor and a built environment professor at the Jomo Kenyatta University of Agriculture and Technology.

This mirrored the major opportunities for scaling the impact of malaria prevention initiatives. The approach was informed by an engineering design process (Ertas and Jones, 1996): 1) identify and research the need or problem; 2) develop possible solutions; 3) test and evaluate solutions using a prototype; 4) communicate and redesign the solution; and 5) finalize the design.

The research design adopted for the first phase had three main steps through which a root cause analysis was performed to: 1) characterize the factors contributing to either success or failure in the existing strategies; 2) identify opportunities for education and engagement within intervention strategies; and 3) develop recommendations for concerted effort in the future (see Figure 6).

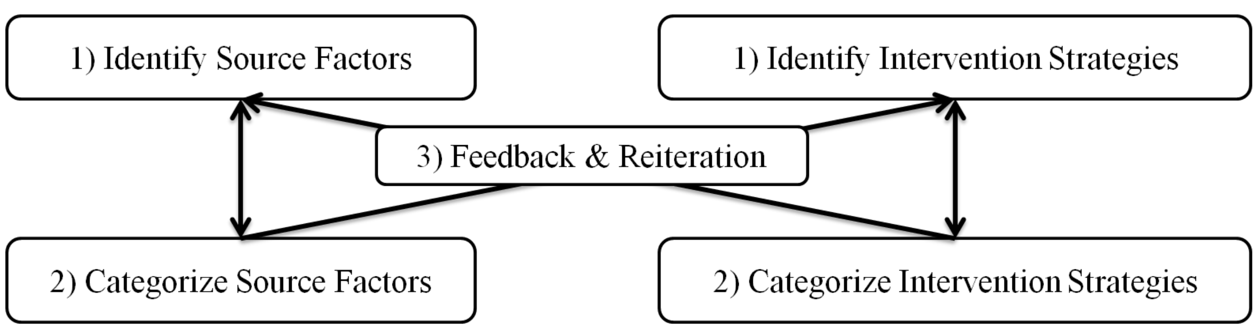

Figure 6: Three-Step Process Model

2.2.1 Source Factor and Intervention Identification

This first step focused on the identification and characterization of two components necessary for generating data. Variables that result in the spread of malaria were characterized as source factors, which were determined from the literature. As shown in Table 3, twenty source factors were identified.

Table 3: Source Factor List (Step 1)

1. Antibiotic resistance	8. Higher relative humidity	15. Low standard of living (e.g., socioeconomic status)
2. Artificial breeding sites	9. Increased rainfall (precipitation)	16. More excavated areas causing open surface water bodies
3. Building envelope modifications (modifying size/placement of openings)	10. Increased temperature	17. Urban agriculture practices
4. Changes in global wind pattern	11. Inlets/outlets for air transfer and ventilation	18. Poor housing material
5. Deforestation from land use	12. Insufficient government/NGO funding	19. Urban agriculture practices
6. Desertification and drought	13. Lack of health education (ex. hygiene practices, blood transfusion)	20. Urbanization
7. Geographic residence (e.g., urban, peri-urban, rural, river, coast, altitude)	14. Lack of synergy among institutions/ organizations	

Based on a comprehensive list of both successful and unsuccessful interventions, a list of key intervention strategies was generated. The generation of this list was based on themes that featured prominently in the literature review or were globally scaled for implementation. Strategies that are in pilot stages of research or implementation were also reviewed. Examples include cutting bush structures to a standard size, using a mosquito-sock trap, or genetically modified mosquitoes. Five major intervention methods that are prominent in the academic or implementation field were identified and are as shown in Table 4.

Table 4: Intervention Strategy List (Step 1)

1. Screened eave tubes (SET)
2. Artemisinin-based combination therapy drugs (ACT)
3. Insecticide treated bed nets (ITN)
4. Indoor residual sprays (IRS)
5. Improved sanitation programs

2.2.2 Gap Analysis

The source factors from Table 3 can be attributed to triggers that can be influenced by three disciplinary sectors: the built environment, public health, and climate change. Descriptions of examples of how each sector may limit the mitigation of malaria are outlined below and also detailed out further in Table 5:

1. *The design and construction of the built environment:* Sites of stagnant water and debris can contribute heavily to the propagation of the malaria vector;
2. *Global health agencies and intervention programs:* vector resistance to antibiotics due to evolution of new genetic strains results in less effective anti-malarial drugs, an increase in the spread of *Plasmodium falciparum*, and a decrease in the effectiveness of intervention methods, and;
3. *Climate change*: increased temperature can promote the breeding habitat of malaria larvae, resulting in favorable environments for mosquito breeding.

Table 5: Categorized List of Source Factors (Step 2)

Built Environment	Global Health	Climate Change
1. Artificial Breeding Sites	1. Antibiotic resistance	1. Changes in global wind pattern
2. Building envelope modifications (modifying size/placement of openings)	2. Geographic residence (e.g., urban, peri-urban, rural, river, coast, altitude)	2. Deforestation from land use
3. Inlets/outlets for air transfer and ventilation	3. Insufficient GOV/NGO funding	3. Desertification and drought
4. More excavated areas causing open surface water bodies	4. Lack of health education (ex. hygiene practices, blood transfusion)	4. Higher relative humidity
5. Poor housing material	5. Lack of synergy among institutions/ organizations	5. Increased rainfall (precipitation)
6. Urbanization	6. Urban agriculture practices	6. Increased temperature
	7. Low standard of living (e.g., socioeconomic status)	7. Pollution (poor indoor air quality)

Table 6 categorizes the intervention methods identified into two sectors. A category for climate change was not included because there are no prominent intervention methods focused primarily on climate change factors.

Table 6: Categorized List of Intervention Strategies (Step 2)

Built Environment	Global Health
1. Screened eave tubes (SET)	1. Artemisinin-based combination therapy drugs (ACT)
	2. Insecticide treated bed nets (ITN)
	3. Indoor residual sprays (IRS)
	4. Improved sanitation programs

2.2.3 Feedback and Iteration

Each intervention strategy was traced back to a source factor. A further analysis was performed to establish the nature of the relationship between each source factor and the associated intervention method where applicable based on an assessment of relevancy. This analysis was also done to determine the extent to which the source factor in question could result in either the success or failure of the intervention strategy. The purpose was to improve the understanding of the relationship between the source factors and intervention methods in each case. For example, a growing population triggers an increased demand for ITNs as an intervention strategy. This is because increased urbanization triggers an increased need for living space, causing increased design and construction activities. This is known to increase the risk of malaria infection. The affordability of an ITNs will have a direct bearing on their update, particularly among communities in the lower socio-economic groups. Clearly, urbanization serves as a reinforcing factor on constraints to the use of ITNs as an intervention strategy.

Relevancy assessments were performed on both the built environment intervention strategies and global health interventions strategies (see Table 7). The red cells indicate a negative causation in the propagation of malaria, green indicate a positive causation, and yellow cells indicate no (or unknown) relationship between the source factor and intervention strategy in question. The assessment was done in a reiterative manner, a core principle of the engineering design process; as new information was received, additional values for the relevancy assessments were created. A documentation of all the data that was created has been included in the Appendix.

Table 7: Section of Relevancy Assessment Matrix (Step 3)

	Built Environment Intervention Strategy	**Global Health Intervention Strategy**
	1. Screened eave tubes (SET)	2. Artemisinin-based combination therapy (ACT)
Built Environment Source Factors		
1. Artificial Breeding Sites	The mechanism of a SET requires a wall that separates an interior from an exterior. Although these tubes may not be used for breeding sites like drains, gutters, swimming pools, or tire tracks (De Silva and Marshall, 2012) placing a treated screen on these types of areas can open new, innovative solutions to preventing malaria in those sites, such as electrostatic coating (Okumu 2017)	More larvae development results in greater mosquito population density, resulting in uneven distribution of therapy needed and greater number of individual at risk for disease.
2. Urbanization	Due to the scalability of eaves tubes, there must be a focus on high-risk groups that serve as priority, before the intervention technologies are scaled to the entire community (Okumu 2017)	Increased population results in greater demand for this product.
Global Health Source Factors		
1. Low standard of living (ex. socioeconomic status)	Low SES to the extent of homelessness within poverty may occur in urban regions. Poverty can result is the greatest risk factor towards malaria. Poverty reduces opportunities to a formal education, which reduces chances to get a good job, recycling into increased poverty. (Adefemi et al., 2015)	Because there are problems related to affordability and accessibility of this drug, those of low SES who already suffer the financial burden of disease treatment are further at risk.
2. Geographic residence (ex. urban, peri-urban, rural, river, coast, altitude)	Malaria is transmitted by different *Anopheles* species, which can vary by geographic environment. Some vectors are more dominant than others. Therefore, more SETs should be implemented in regions with higher prevalence.	Those in regions where the species of *Anopheles* is more prevalent will increase the demand, resulting in a greater need for affordable and accessible therapy drugs.
Climate Change Source Factors		
1. Deforestation from land use	Deforestation increases prevalence of the malaria vector. Because buildings are made by initial deforestation, the increase in homes requiring SETs mirrors the increase in the deforestation.	Dispersal of the vector to different geographic regions result in greater need to outsource the drug to new communities, which results in difficulty for those unable to afford or access the drug.
2. Increased rainfall (precipitation)	Increased prevalence of the Anopheles vector will result, causing greater need for SETs.	More favorable habitat for reproduction. More generations of vector will result in antibiotic resistance to drug, resulting in less effective ACT drug.

The data matrix analyzes the relationship between source factors from each of the three categories with one intervention strategy from the built environment and global health industries.

2.3 Phase Two: Validation

The focus here was to validate the results from the analysis performed in Phase 1 through obtaining input from East Africa-based built environment professionals. An Institutional Review Board–approved survey was given to professionals who had work experience in the built environment. The design of the questionnaire was informed by the source factors described in the previous section, along with support from literature review and consideration for each stage within the construction life cycle.

The survey had ten multiple choice and three open-ended questions. It was distributed both electronically and in print to built environment professionals with design and construction experience in urban Kenya. The sample size was based on the threshold for the minimum sample size of thirty respondents for a pilot survey (Johanson and Brooks, 2009).

The subsequent paragraphs identify the specific multiple choice questions that were included in the survey. A Likert scale was used for the multiple choice questions to capture the strength of opinions of those observed. The order of questions matched the order in which risk factors within those questions would appear in the construction life cycle.

1. *Each aspect of designing a building has a direct bearing on health.* This question captures a holistic view of the design process. It is related to the fact that built environment professionals have multiple opportunities to make significant contributions to the mitigation of malaria.
2. *The size, location, and geometry of openings has a direct impact on the spread of vector-borne diseases (VBDs).* This question is related to the significance of openings as an intervention strategy from a public health perspective, as a large number of programs focus on this theme. From a built environment perspective, building openings are most

economically effective when factored in a malaria mitigation strategy during early stages of a project.

3. *The selection of materials for the building envelope is a critical success factor for mitigating the risk of VBDs for the end users.* It has been observed that the use of traditional building materials result in a higher number of mosquitoes inside the building. Given that the specification of building materials is during the early stages of a project, it can be a good converging point for discussions on synergies between public health and built environment professionals.
4. *Public health specialists, urban planners, and building code approvers can play a significant role in promoting positive health outcomes throughout the entire life cycle of buildings.* This question was used to address the overall hypothesis for this research that built environment professionals working closely with practitioners from other different disciplines can contribute to the mitigation of VBDs such as malaria at scale in a more sustainable manner.
5. *There should be a standardized way of identifying and documenting health risks during the building permit approval process.* This question mirrors not only interviews that were conducted, but also past methods of intervention in the Panama Canal case study. Historically, certain intervention methods that included cross-disciplinary communication were successful, and this question seeks to validate the regulatory component of those strategies in today's context.
6. *Human comfort and indoor air quality has a direct bearing on the spread of VBDs*. The question was derived from results of the relevancy assessments performed in Phase 1,

which showed a positive relationship between factors related to weather-related factors such as temperature and their effect on the spread of VBDs.

7. *Brick durability has a direct bearing on the spread of VBDs.* There is a positive influence of material selection on the propagation of VBDs. This question was used in order to gauge if built environment professionals consider both design and construction as a cycle of cause-and-effect factors for VBD propagation in the form of building materials such as bricks.
8. *Excavation increases the occurrence of vectors and thereby the risk of VBDs.* Many studies have indicated that open surface water bodies from excavated sites increase the occurrence of vectors in the built environment. This question explores excavation work, the most expensive cost element in most construction projects, as a converging theme for synergies in the fight against malaria.
9. *The physical environment around the construction site can increase the risk of VBDs to the workers and occupants of nearby buildings.* This question relates back to the physical location of a building project as a contributing factor to the risk of malaria.
10. *Building management practices such as retrofits, repairs, or modifications to openings through adding screens should be periodically done to ensure their effectiveness and efficiency in controlling VBDs.* Many studies suggest that retrofits and repairs are influential in mitigating the spread of malaria. From a built environment perspective, there is an opportunity to design building in a way that factors in the need to adapt to changing conditions.

The survey also had three open-ended questions outlined below.

1. *What is the title of your occupation?* This was useful for developing an understanding of the diversity of fields that were represented as well as whether one field was represented more often than others.
2. *How many years have you been working in the built environment field?* This could assess the extent to which practical field experience affected the respondents' views.
3. *How can members of the design and construction team be more involved in the control of vector-borne diseases? Please explain your thoughts below.* This was included to identify any recurring themes or interests that respondents were not able to convey in other questions in the survey.

Chapter 3 Data Analysis and Results

The goal of this chapter is to analyze the results of Phase 1 and 2. The results of Phase 1 examine the relationship between the source factors and intervention methods for different sectors. The results of Phase 2 include both a descriptive and a statistical analysis of the responses to each multiple choice question in the survey. The results of Phase 2 also include a summary of sub-themes determined from the open-ended questions.

3.1 Results from Phase One

A web of causation approach to was used to map the interdependencies and interlinkages in the risk factors that result in the spread of malaria. The critical interdependencies and interlinkages of the main source factors were mapped onto a matrix of secondary data. In addition, intervention methods were traced back to risk factors embedded in various disciplines. A relevancy and impact assessment of these risk factors was performed.

There were 100 assessments of relevancy (see Appendix section) performed based on cause and effect relationships drawn from both the literature reviews and the semi-formal interviews. The assessment focused on the analysis of the 20 source factors and 5 intervention methods. The results included positive, negative, and neutral relationships between risk factors and intervention methods. The percentage of negative relationships observed are identified on Table 8.

Table 8: Percentage of Negative Relevancy Assessments (Step 3)

	Intervention Methods	
Source Factors	**Built Environment**	**Global Health**
Built Environment	100 %	88 %
Global Health	71 %	93 %
Climate Change	86 %	68 %

It was established that 100 % of built environment-related source factors could contribute to the spread of malaria by negatively influencing built environment-related intervention methods. Similarly, 93% of global health-related factors could negatively influence global health-related intervention methods. These high correlations are expected, as intervention methods are developed to mitigate risk factors in their respective discipline. Additionally, the percentages of global health-related and climate change-related factors that could negatively influence built environment–related intervention strategies were high. The pattern is similar when comparing built environment–related and climate change–related factors with global health–related intervention strategies. It was further established that observed lack of effectiveness (based on rising costs) in malaria intervention strategies as discussed in a preceding section can be attributed to 83 failure modes.

Results shown in Table 8 show a positive correlation between climate change, population growth, rapid urbanization and the spread of vector-borne diseases. Inadequate housing, which includes poor quality buildings that also lack infrastructural services for water, sanitation, and sewage, thus provides breeding sites for vectors such as mosquitoes. The increase in demand for VBD intervention strategies such as ITNs results in greater need for scalable, low-cost strategies. These factors represent major opportunities from which actors and players of both the global health and built environment industries can create synergistic partnerships.

3.2 Results from Phase Two

The primary focus of phase two was to validate the findings from Phase 1 by seeking input from East African-based built environment professionals. A survey was administered to 34 respondents.

3.2.1 Respondents' Profile

The respondents described themselves as Architects, Quantity Surveyors (Construction Cost Consultants), Developers, Structural Engineers, Civil Engineers, Construction Project Managers, and Students. They had 2 to 40 years of practical experience. The mean and median for years of experience were around 15 years with a standard deviation of around 10.5 years. Overall, the average respondents in this study had about 15 years of experience in the Kenya-based design and construction field.

3.2.2 Multiple Choice Results

All multiple choice data is summarized in Table 9 and graphically represented in Figure 7. As shown in Figure 8, most people agree with the given statements. Overall, Strongly Agree and Agree were selected 133 and 125 times, respectively. "Neutral" was selected 56 times, implying that respondents may not have considered or are not informed enough to know about certain topics. "Disagree" and "Strongly Disagree" were selected 19 and 7 times, respectively.

Table 9: Summary of Multiple Choice Responses

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Each aspect of designing a building design has a direct bearing on health.	19	12	3	0	0
The size, location, and geometry of openings has a direct impact on the spread of vector-borne diseases (VBDs).	13	15	3	3	0
The selection of materials for the building envelope is a critical success factor for mitigating the risk of VBDs for the end users.	8	16	8	1	1
Public health specialists, urban planners, and building code approvers can play a significant role in promoting positive health outcomes throughout the entire life cycle of buildings.	22	11	1	0	0
There should be a standardized way of identifying and documenting health risks during the building permit approval process.	19	14	0	1	0
Human comfort and indoor air quality has a direct bearing on the spread of VBDs.	15	14	4	1	0
Brick durability had a direct bearing on the spread of VBDs.	4	7	14	6	3
Excavation increases the occurrence of vectors and thereby the risk of VBDs.	2	13	11	5	3
The physical environment around the construction site can increase the risk of VBDs to the workers and occupants of nearby buildings.	15	13	6	0	0
Building management practices such as retrofits, repairs, or modifications to openings through adding screens should be periodically done to ensure their effectiveness and efficiency in controlling VBDs.	16	10	6	2	0

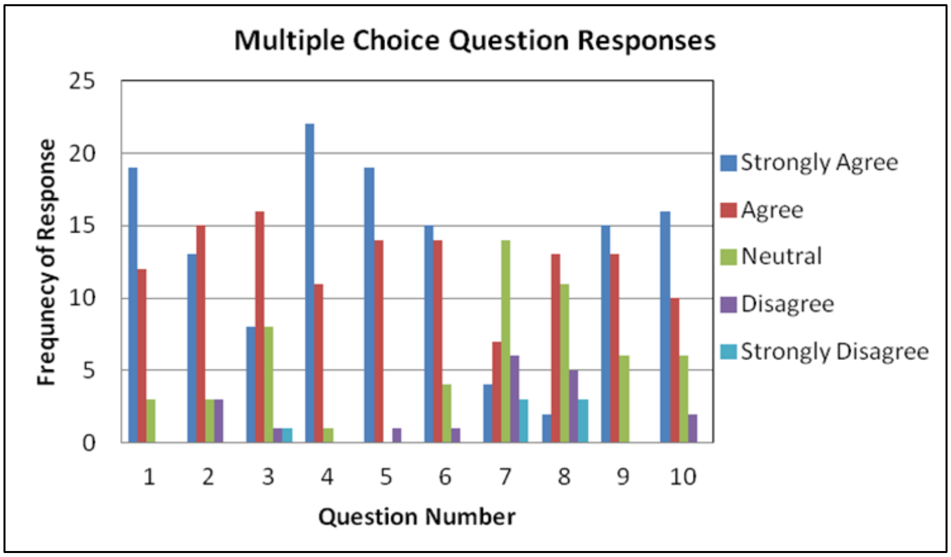

Figure 7: Answer Frequency per Each Question

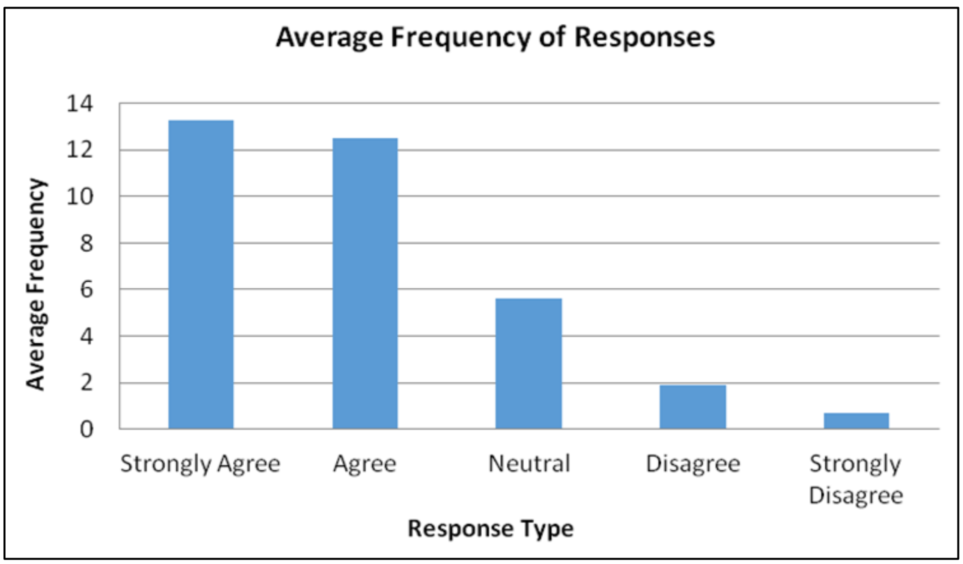

Figure 8: Average Frequency of Each Response for Multiple Choice Questions

3.2.3 Analysis of Multiple Choice Results

The responses to each of the multiple choice question were evaluated against the source factor propagation scenarios that were previously presented in Table 7. The emerging relationships that were identified as part of the mapping that was done have been outlined in the subsequent paragraphs.

1. "Each aspect of designing a building design has a direct bearing on health."

The percentage of responses selected as Strongly Agree, Agree and Neutral were 56 %, 35 %, and 9 %, respectively. Based on the categorizations of literature related to built environment health that were presented in Table 2, all facets of building design can either propagate or mitigate the spread of malaria. The built environment professionals' views on the extent to which the design of building elements and components on health can therefore have a significant impact on the fight against malaria. Because most responses were agreeable, it can be inferred that many built environment professionals would be receptive to dialoguing about the unique role they can play in mitigating the spread of VBDs through design decisions. It was also observed that 10% of the respondents selected Neutral. This suggests that there may be a need to disseminate more information on healthy buildings including the link between buildings and the risk of VBDs.

2. "The size, location, and geometry of openings has a direct impact on the spread of vector-borne diseases (VBDs)."

The percentage of responses selected as Strongly Agree, Agree, and Neutral were 38 %, 35 %, and 9 %, respectively.   Many respondents agreed with this statement, which aligns with trends published in the leading journals from the literature review. The proportion of respondents who selected Neutral suggests that the control of VBDs may not be a significant consideration during the design process.

3. "The selection of materials for the building envelope is a critical success factor for mitigating the risk of VBDs for the end users."

The percentage of responses selected as Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree were 24 %, 47 %, 24 %, 3 %, and 3 %, respectively. Over 75 % of respondents did not strongly agree with this statement and around 30 % did not agree to any extent; this suggests a need for awareness creation to encourage the consideration of this factor during the specification of building materials. There is a link between the use of traditional building materials and an increase in the occurrence of VBD (Tusting et al., 2015). Poor housing quality can also contribute to the incidence of malaria (Liu et al., 2014). Selection of material is most effective when done during the design phase of the construction life cycle. The responses suggest that there is a missed opportunity for the specification of building materials to be used as a strategy for mitigating the risk of malaria infection. There is therefore a critical need to invest in awareness creation campaigns.

4. "Public health specialists, urban planners, and building code approvers can play a significant role in promoting positive health outcomes throughout the entire life cycle of buildings."

The percentage of responses selected as Strongly Agree, Agree, and Neutral were 65 %, 33 %, and 3 %, respectively. The interdisciplinary nature of healthy buildings is evident from the discussion in a previous section on the different ways through which multiple sectors contribute to the underlying risk factors. As outlined in the results of the categorization of existing research in the field on Table 2, a drive for positive health outcomes requires interdisciplinary effort at each stage in the construction life cycle. Questions 4 is one of the two questions that received the largest percentage of agreeable responses. This shows that built environment professionals are interested in contributing to health outcomes through building design, construction, and modification. This finding supports the hypothesis that there is an opportunity to increase the impact of efforts directed at mitigating the spread of VBDs through leveraging decision making within the built environment.

5. "There should be a standardized way of identifying and documenting health risks during the building permit approval process."

The percentage of responses selected as Strongly Agree, Agree, and Disagree were 56 %, 41 %, and 3 %, respectively. When done in a planned and structured manner, the built environment-related risk factors that contribute to the spread of malaria can be reduced to a minimum or even completely eliminated. This was exemplified in the best practices used during the construction of the Panama Canal (see Section 1.2). Public health controls such as sanitation and work-related cautionary procedures were standardized throughout the construction project, which led to major success in controlling the spread of malaria (Centers for Disease Control and Prevention, 2015). Standardized efforts have the potential of promoting positive health outcomes for built environment health. This was the second question with the highest number of agreeable responses. It can be inferred that built environment professionals have an interest in a knowledge base that can be accessed easily during the formative stages of a project. It has been observed that half of them did not select the strongly agreed option. This suggests that there is a need to increase their awareness with respect to the most effective methods for identifying and managing built environment -related risk factors that contribute to the incidence of malaria..

6. "Human comfort and indoor air quality has a direct bearing on the spread of VBDs."

The percentage of responses selected as Strongly Agree, Agree, Neutral, and Disagree were 44 %, 41 %, 12 %, and 3 %, respectively. Most people will feel comfortable at room temperature, which is between 20 °C to 22 °C. The sample size consists of respondents who have experience in the urban parts Kenya that have milder temperature conditions, where the annual monthly temperatures range between 23 °C to 26 °C (Climate Change Knowledge Portal, 2016). They are therefore more sensitive to temperature fluctuations outside of the thermal comfort zone and its impact on the habits of the occupants. Given that houses in this context rely on natural ventilation, the occupants of buildings that are deemed to be "too hot" with respect to being outside of the thermal comfort zone, will spend more time outdoors where the risk of malaria infection is higher.

7. "Brick durability has a direct bearing on the spread of VBDs."

The percentage of responses selected as Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree were 12 %, 21 %, 41 %, 18 %, and 9 %, respectively. Cracked or damaged bricks as well as less durable masonry made with traditional building materials increase the ease with which mosquitoes can access homes. This can be compounded by weather elements such as moisture, which can increase the likelihood for cracks or degradation. This question received the lowest percentage of agreeable responses, as most respondents were neutral about the public health effects of brick durability. This may be because perhaps they did not perceive brick durability as intended. Their responses suggest a need for awareness creation.

8. "Excavation increases the occurrence of vectors and thereby the risk of VBDs."

The percentage of responses selected as Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree were 6 %, 38 %, 33 %, 15 %, and 9 %, respectively. Phase 1 of the literature review revealed that excavated sites increase the prevalence of mosquitoes by creating favorable breeding environments for mosquitoes - they prefer small, stagnant pools of water (Impoinvil et. al, 2008). Going by the response, excavation as a source factor for VBD propagation does not appear to be a design consideration that built environment professionals take into account. Their responses suggest that there is a need for a two-way conversation between public health and built environment experts. This can be facilitated in a more scalable manner through a knowledge sharing platform.

9. "The physical environment around the construction site can increase the risk of VBDs to the workers and occupants of nearby buildings."

The percentage of responses selected as Strongly Agree, Agree, and Neutral were 44 %, 38 %, and 18 %, respectively. Based on the results of Phase 1, there is a positive relationship between malaria transmission and urban settings due to factors such as agriculture, water pipes, tire tracks, drains, ditches, gutters, hygiene, waste collection, and travel (De Silva and Marshall, 2012). Executing a large projects sites in close proximity to existing buildings can propagate these risk of malaria infection. This risk is increased by the presence of stagnant water bodies, increased debris, and other favorable breeding sites for mosquitoes. Many respondents were neutral, which suggests that there is an opportunity to increase the impact of malaria mitigation efforts through education built environment professionals on site selection as a source factor..

10. "Building management practices such as retrofits, repairs, or modifications to openings through adding screens should be periodically done to ensure their effectiveness and efficiency in controlling VBDs."

The percentage of responses selected as Strongly Agree, Agree, Neutral, and Disagree were 47 %, 30 %, 18 %, and 6 %, respectively. Protective features against mosquitoes can be integrated into retrofits and repairs by using insecticide treatments or screens. Routine and planned maintenance work is part of best practice in the field of facilities management. It is now widely acknowledged that design decisions made during the early stages of the construction life cycle can increase both the effectiveness and efficiency of the required work. This could be a valuable converging theme for the public health and built environment professionals to deliberate on a set of best practices for performing building retrofit, repair or any other modification work in a way that contributes to mitigating the spread of VBDs in the most efficient and effective manner.

3.2.4 Multiple Choice Results Statistical Analysis

A quantitative analysis was conducted to serve as possible support and evidence of opportunities for education and engagement in the design and construction industry about the involvement of public health-related strategies in built environment-related malaria mitigation.

The data observed is Likert-type data rather than Likert-style data. This is because the questions are independent of one another. Historically, there is debate among social scientists about the statistical analysis test to perform on Likert-style questionnaires. Acceptable forms include a chi-square test and a one sample t-test. A chi-square test analyzes the difference between observed and expected results. In this case, the expectation is that there is a strongly agreeable opinion about the statements given in the survey for the multiple choice questions. A t-test compares an unknown (new) set of data with a known population mean. The debate arises through the interpretation of whether Likert-style data is used as nominal (qualitative) or interval (numeric) data.

A one-sample, or paired t-test, was considered to further understand to which direction the data would statistically differ, if so. Considering a paired t-test ($n = 34$, $p < 0.05$), each response type was assigned under a graded value: 0 for Strongly Agree, 1 for Agree, 2 for Neutral, 3 for Disagree, and 4 for Strongly Disagree. The null hypothesis was stated that there is an opportunity for education and formal engagement among design and construction professionals about VBDs like malaria in the construction life cycle. In other words, there is a statistical difference between the expected answer of Strongly Agree to every question and the observed answers. The analysis for each question resulted in a rejection of the null hypothesis, suggesting that any existing knowledge gaps were not detected.

The major reason for lack of statistical significance is the small sample size of only 34 respondents. Because the survey was part of a pilot study for this research, a greater sample size would offer greater certainty or external validity for this study. Also, the survey measured occupation and years of experience as variables that may have mediated responses. Based on the statistical results, they may not have a significant effect on the results due to the wide age range and the moderately varying types of occupations. Possible areas for future statistical study could include studying the mediating effect of other variables such as history of past experiences or related projects in design, construction, and health.

3.2.5 Results and Analysis of Open-Ended Question

The respondents were also invited to comment on the following open-ended question: *How can members of the design and construction team be more involved in the control of vector-borne diseases? Please explain your thoughts below.* Based on 32 open-ended responses, five major themes are presented in this work, as described below.

1. Increased awareness through education and training;
2. Increased oversight through policy, regulations, standards, or codes;
3. Increased focus on the relationship between design and construction that leads to effective intervention methods;
4. Increased collaboration in an interdisciplinary team, and;
5. Increased ventilation to support respiratory health.

10 respondents underscored the need for education and training on the opportunity to control VBDs through built environment design decisions. The awareness creation needs can be addressed through presentations at conferences and seminars, or through publications in industry journals. 5 respondents underscored the value of having professional and regulatory organizations provide oversight of management and employees in the field. They specifically identified the need for standards, design checklists and guidelines as well as a provision in the code approving process for ensuring mitigation of VBDs is considered throughout the design and construction process. 12 respondents called for more efforts to be directed at encouraging a more holistic assessment of the adverse impact of the built environment on health through effective intervention strategies. These included cutting grass, minimizing dust, spraying when needed, avoiding puddles, and protecting the built environment from damp areas. 7 respondents

identified opportunities for sensitization and awareness creation on the importance of working with a diverse stakeholders across different disciplines. This ranged from health experts for providing advice on best practices to policy representatives for increasing visibility of the issue. 5 respondents pointed out the need to invest more efforts in strategies that can improve indoor air quality. They demonstrated a good understanding of the relationship between inadequate ventilation in buildings and respiratory diseases. Designers in the built environment field are uniquely positioned to design an optimization strategy for the size and placement of openings such as windows to ensure that the need to minimize the ease with which mosquitoes access homes does not result in inadequate ventilation to the point of increasing the risk of respiratory illnesses. In the East African context, buildings are naturally ventilated. It is, therefore, important that modifications to openings as part of malaria prevention efforts are informed by the minimum thresholds for air exchange rates between the interior and exterior. The latter is necessary for reducing indoor air pollutants and other risk factors that can result in respiratory illnesses such as asthma.

Chapter 4 Discussion and Conclusion

The objective of this research is to examine the extent to which design decisions in the built environment can improve malaria mitigation efforts. The results from literature review, Phase 1, and Phase 2 are presented as a summary of key findings. Recommendations about leadership in diverse disciplines and the value of mapping VBD control onto the construction life cycle are discussed. Concluding thoughts and future direction for this research are included.

4.1 Summary of Key Findings

Current trends in research of built environment-related malaria prevention include the use of screened eave tubes, an intervention method studied in Phase 1. There are some promising results on the impact of variables such as adjustments to size and geometry (Sternberg et al., 2016), use of insecticide treated eave tubes (Ogoma et al., 2009), and effect of varying location (Waite et al., 2016). It is also known that effective decision making based on these factors have the potential to translate into high financial and economic cost savings during the early stages of the construction cycle. When implemented in a reactive manner through retrofitting during the facility use stage, there is both a missed opportunity to reduce the incidence of malaria and higher financial burden on the building owner.

The extent to which built environment-related factors can be used to mitigate the spread of malaria during the construction life cycle requires a deeper understanding of several risk factors present during the entire construction life cycle. Changes in global wind pattern and increased rainfall are examples of risk factors that propagate the spread of the disease. The risk of malaria infection is higher at night, given that the *Anopheles* mosquitoes in Sub-Saharan Africa mainly bite between 10 p.m. and 4 a.m. when most people are indoors (Tusting et al., 2016). Weather-related factors such as increased precipitation, relative humidity, and temperature conditions can also create a more suitable habitat for the malaria vector (Climate Nexus, 2015). A study focusing on land use and malaria transmission in Uganda found that for every 1 °C increase in average minimum temperature, there was a 77% increase in *Anopheles gambiae* per each model house (Lindblade, 2000). When such favorable conditions coincide with the construction phase of a project, the breeding potential for malaria-causing mosquitoes also increases significantly. The construction phase is characterized by pools of stagnant water developing in areas of intense excavation (Reiter, 2008) and work areas with earth removal work (Lipscomb, 2006). The sources of the water can be leakages from temporary water supply points and storm water that is not drained promptly (Yhdego and Majura, 1988).

Some of the ways through which the built environment contributes to the risk of malaria transmission become more apparent during the facility use phase. Malaria-causing mosquitoes access the building through the inlets and outlets included in the design of the building envelope to allow air exchanges between the exterior and the interior. The malaria mitigation initiatives are directed at minimizing the ease with which mosquitoes access the interior of the buildings by focusing on reducing the size and number of openings (Sternberg, 2016). It is critical to engage built environment design professionals to ensure that the desired building modifications do not result in undesirable effects. Because indoor air quality (IAQ) and comfort of the occupants predicates directly on having optimal air exchanges, changes to the openings can result in unfavorable conditions for humans (Huizenga et al., 2006). Building occupants in malaria-prone areas rely on natural ventilation to attain optimal IAQ. Reducing air exchanges has a direct impact on thermal comfort of the occupants encouraging them to spend more time outdoors, particularly in evenings, where they have a much higher risk of being bitten by a malaria-causing mosquitoes. It is also known that poor IAQ can increase the risk of respiratory diseases (Ezzati and Kammen, 2002). Having the right IAQ is also important for managing air-borne pathogens. Therefore, it is important to align all decisions that affect the size, exact location, and number of openings with the principles of building physics. Ensuring that optimal ventilation rates are attained requires an in-depth understanding of the building as a system of system. Mitigating the risk of malaria from a built environment perspective is, therefore, a complex undertaking. Each decision has many associated linkages and interdependencies. Outside of working in a synergistic manner with the experts in the design and construction of buildings, any building-related intervention will be based on a partial view of what constitutes a healthy building.

The complexity of mitigating the risk of malaria transmission through managing built environment–related factors is evident from the exemplary scenario depicted in Figure 9.

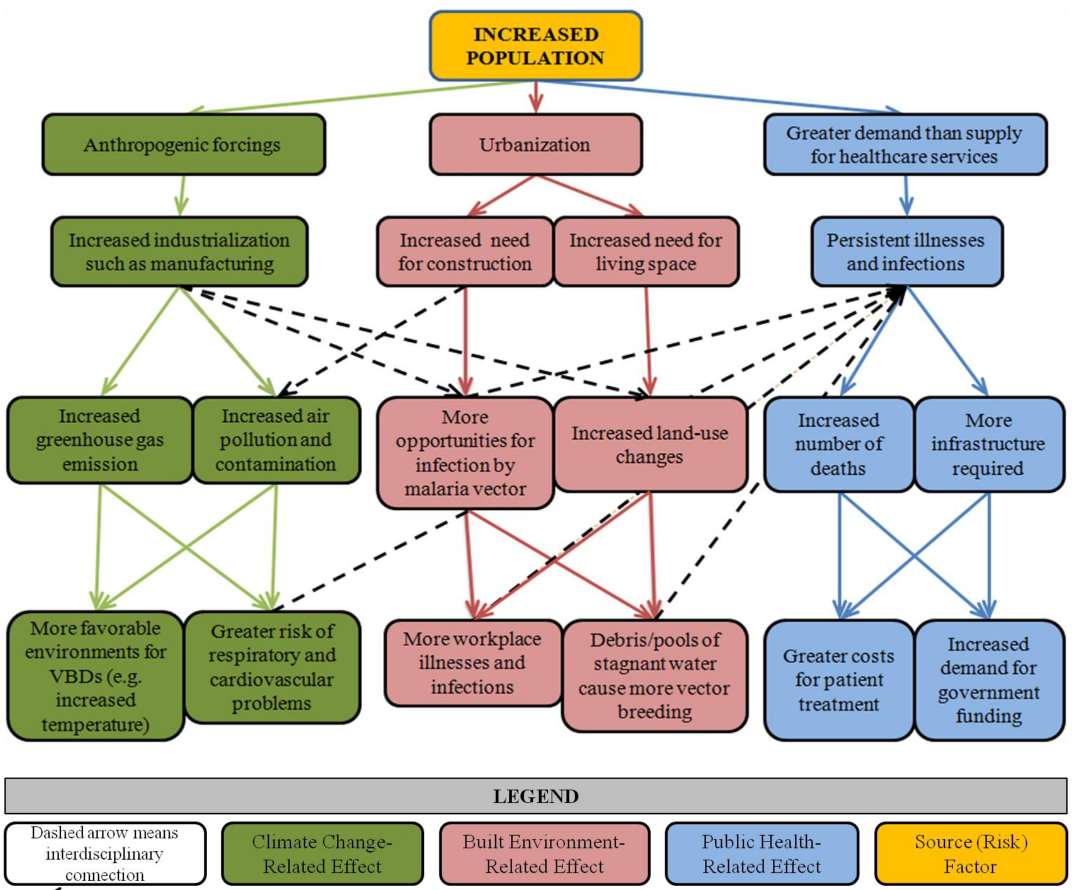

Figure 9: Source Factor Propagation Scenario

Rapid increase in population results in increased demand for the Earth's energy budget. Human activities such as agriculture and transportation technology serve as factors that increase greenhouse gas emissions and contaminate the atmosphere with pollutants. These risks increase the number and severity of human health complications such as respiratory and cardiovascular illnesses. Air contamination also causes factors such as temperature, rainfall, and precipitation to increase beyond expected patterns. These climate change-related factors provide more breeding sites and faster maturation times for mosquito larvae (Nabi and Qader, 2009). The effect of weather-related factors are thus compounded by climate change. Population increase will continue to propagate the spread of malaria due to its association with climate change-related risk factors.

Rapid population growth results in increased demand for housing. Given that the population is growing more rapidly in the already congested urban areas, the population density is also increasing rapidly. The rapid growth in population ultimately results in land use changes with previously forested areas being cleared to make room for human habitation. More events in the construction life cycle create more opportunities for vector–human interaction. This association, propagated by factors like debris and stagnant water pools, can cause more illness as more land is used for construction. As population in villages and towns and the building of dams increases, humans will get closer to mosquito breeding grounds (Nabi and Qader, 2009). This increase in infection will persist because of the relationship between the built environment and malaria.

An increase in population results in more health problems due to increased human–human contact and human–environment contact. Greater demand for healthcare services puts additional pressure on the health care system in malarious regions that are already resourceconstrained. The increase in population contributes to an increase in the number of reported VBD-related illnesses and deaths. There is also an increases in the cost of healthcare that can be attributed to rapid population growth rates. This could partially explain the escalating expenses associated with malaria prevention that were discussed in the introductory chapter.

The complexity of the mitigation of malaria is captured by the interdisciplinary nature of risk factor propagation throughout different disciplines. Anthropogenic activities traditionally associated with climate change such as coal mining and energy consumption from transportation and trade affect the built environment. This is due to deforestation and changes in land use, which are influential components of the primary stage of the construction life cycle. Increased construction creates greater opportunities for workplace illnesses that can increase the demand for public health resources. This reinforces the cause and effect relationships that persist under the public health context described above. Each risk factor propagates within and across disciplines in unique pathways. Cross-sectoral collaboration is an effective tool for understanding the complexity of these system-in-system interactions.

As previously stated, there has been a significant increase in the amount of money spent in mitigating the risk of contracting malaria with, for example, Global Fund spending as much as USD 9.1 billion in 2016, a 90% increase from the funding that was provided from 2006 to 2016 (Global Fund Malaria Financials, 2017). During this period, the population of world grew from 6.60 billion to 7.44 billion. For Kenya and Tanzania, the population grew from 36 to 48 million and 39 to 55 million, respectively (World Bank, 2018). The resulting increased exposure to the *Anopheles* vector increases the pressure on healthcare resources through expenses such as hospital utilities, medical supplies, and government spending for research funding, which has a direct bearing on the development timeline for new anti-malarial drugs that combat antibiotic resistance.

Population growth is one of many source factors that can trigger consecutively larger impact at scale across sectors. The wide range of risk factors involved require a similarly wide framework for successful intervention. The use of a decision network tool can address these major causative factors in a systemic manner through encouraging professionals in overlapping industries to discuss the pertinent issues in a way that mutually reinforces what each discipline is uniquely positioned to do both efficiently and effectively.

4.2 Discussion and Recommendations

Because the built environment is a complex system of systems, there are some significant opportunities for education regarding malaria mitigation efforts that need to be addressed before interventions such as building envelope modification can have impact at scale in a sustainable manner. Bridging the existing knowledge gaps requires collaboration across several disciplines. One of the initial priority action items has to be identifying and dissemination information on the specific areas where working in disciplinary silos has resulted in missed opportunities for synergistic action. The work presented in this thesis is directed at doing just that. There is also a need for characterization of the nature of relationships that exists across the known source factors. To the best of the author's knowledge, this is the first study that has examined the sources factors from the perspective of built environment-related design decisions with the goal of mapping existing interlinkages and interdependencies. This can be achieved using the metaphor and model of the web of causation, which is an approach that has been used by epidemiologists in health studies to map primary and secondary factors as well as existing factor-to-factor interactions that may have a reinforcing effect. The authors applied this approach to the built environment–related factors that contribute to the propagation of malaria. The outcome of this endeavor is summarized in Table 10.

Table 10: Opportunities for Collaboration with Leaders from Diverse Areas

Thematic Area	Decision Team Members
Urbanization and Environmental Sustainability	Urban Planners and Designers
Climate Change	Researchers and Advocates
Formal and Informal Safety Practices	Health and Environmental Services
Land Use and Development	Architects and Engineers
Repairs and Retrofits	Engineers, Designers, and Builders
New and Emerging Technologies	Innovators and Humanitarian Entrepreneurs
Leading Global Organizations	WHO, PMI, Global Fund, USAID
Permit Requirements	Code Approvers
Healthy Placemaking	Public Health Scientists
Social Determinants of Health	Social Epidemiologists
Scientific and Medical Research	Clinical Professionals
Government Advocacy and Policy Funding	Budget Planners

The analysis done as part of this research revealed a number of thematic area-specific opportunities for informed design decision making within interdisciplinary teams of overlapping industries. Examples of specific opportunities include collaboration with policy professionals, urban planners, research scientists, and epidemiologists. Table 10 also highlights areas in which built environment specialists are uniquely positioned to make an impactful contribution. For example, public health professionals who specialize in healthy placemaking can champion the exchange of knowledge with built environment professionals by participating in the now commonly run pre-project planning workshop. This would encourage the entire design team to prioritize on the selection of project sites for construction that reduce the risk of malaria propagation.

The analysis also established that there was a need for a knowledge sharing and dissemination platform promoting the kind of cross-disciplinary deliberations that can promote synergy in malaria prevention efforts. The envisioned platform would promote cross-disciplinary collaboration in knowledge creation, while also increasing opportunities through which relevant information could be pushed and/or pulled into a decision support tool for built environment professional at the senior management level.

The information on specific ways through which the built environment can make a positive contribution to malaria prevention should be made available during the conceptual design phase. The impact with respect to cost savings is higher during this phase. There are still other ways through in which a more intentional emphasis on making mitigating the risk of VBDs a priority for design professionals can translate to cost savings in subsequent stages of the construction process. The design of a built asset is often based on some assumptions being made because of unknown variables. There is an expectation that some changes will be made throughout the entire construction phases as more information becomes available (Motawa et al., 2007). This results in requests for revisions to the contract documents that are communicated to the design team through change orders. Information on ways through which design decisions can be leveraged for impact in the fight against malaria can be customized to match the opportunities within the specific construction phase associated with a requested change order.

Clearly, there is a need for knowledge to be shared across different disciplines. The author contends that this need can be addressed through developing a knowledge management framework with the features depicted in Figure 10. This conceptual architecture for what will be used as knowledge management platform once fully developed, is based on the exemplary sources factors for the risk of VBDs that can be linked to decision making during the design and construction of buildings. These factors are discussed in the subsequent paragraphs.

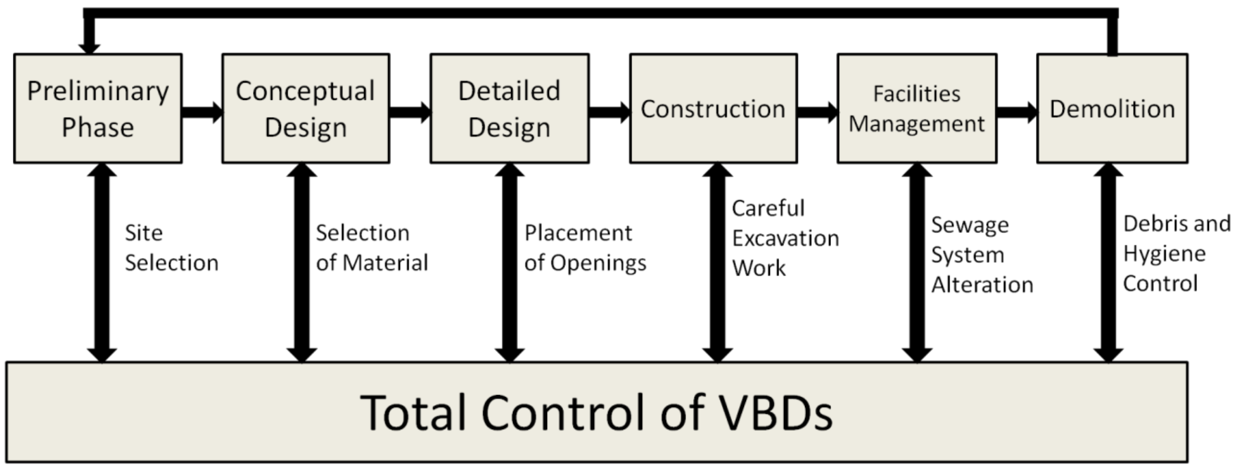

Figure 10: A Knowledge Management Framework for Professionals with Influence in Exchanging Information about VBD Risk Mitigation

Site selection is an important course factor that can be leveraged in malaria mitigation efforts. Project sites that have close proximity to dams, buildings that are dilapidated, and swamps increase disease prevalence. Creating a systematic procedure and checklist to capture all source factors can encourage the design team and building owners to consider the surroundings of potential project sites before any decision that cannot be easily reversed is made.

The appropriate selection of material can address the observed problem of buildings having been constructed using traditional materials and becoming more susceptible to mosquito intrusion. It is worth noting that traditional material are considered to be more sustainable, considering their carbon footprint. The author recommends that rather than encouraging their disuse, efforts should be invested in researching ways through which material science can be used to address the reasons why mosquitoes prefer buildings that have been constructed using traditional materials.

The existing knowledge on specific ways through which openings can increase ease with which mosquitoes can access a home should inform what is largely a natural ventilation-driven optimization strategy used to specify the size and location of windows, doors and vents in new building envelopes.

The development of a strategy for managing pools of stagnant water that form in excavated areas will increase number of favorable sites for mosquito larvae to mature. Having a robust strategy for promptly draining stagnant pools can be factored into existing dewatering strategies. Foundation work usually has a budget for pumping out water during excavation to allow for the construction of foundation elements following heavy rains.

Retrofits, repairs, and building modifications focused on malaria mitigation should consider the impact of indoor air quality and human comfort on the risk of malaria. The facilities management phase also models successful VBD control when material of construction and surrounding moisture are considerations. A knowledge management framework would provide value by sharing proper techniques for installation and appropriate materials for piping in order to ensure durabilty, long lifespan, and minimal need for repair.

The impact of the demolition of a building on the risk of VBD can vary significantly depending on whether or not there is an interest in salvaging some of the material. In general, construction and demolition waste often ends up in landfills, which presents several environmental problems including the creation of favorable breeding conditions for mosquitoes. There is growing interest in shifting the construction industry to a more circular economy through encouraging both recycling and upcycling. The proposed knowledge management platform can leverage this interest to promote awareness on the link between how demolition waste is managed and the risk of VBDs.

Because malaria is a complex problem, it must be addressed through both a bottom-up and top-down approach. In addition to working directly with the built environment professionals as outlined in the preceding paragraphs, there will be a need for the proposed knowledge management platform to have linkages to portals where professionals working in institutions and organizations that have a regional, national and global influence exchange information. These include: 1) Public health forums such as those managed by WHO, PMI, and USAID, which provide worldwide funding and support for actionable intervention methods like SETs, ITNs, and IRSs; 2) Government programs in, for example, the Ministry of Health initiatives that have a presence at both the national and regional level; 3) Professional organizations such as the Architectural Association of Kenya, which have convening power required to disseminate information at scale through conferences, workshops and continued professional educational programs; and 4) Donor organizations and funding agencies such as the Bill and Melinda Gates Foundation, which are increasingly advocating for cross-disciplinary synergies in the fight against malaria.

4.3 Conclusion and Further Work

This thesis has assessed the extent to which design decisions in the built environment can positively affect efforts directed at mitigating the risk of malaria in an East African context. With over 216 million infected cases (WHO) and over USD 9 billion spent (Global Funds) in 2016 to combat malaria, the disease is expected to persist. As population grows rapidly in cities is projected to increase, there is a great need for new cross-disciplinary strategies that work in a synergistic manner.

It is known that the built environment, through features such as openings, can propagate the spread of malaria. The earliest example of built environment-related strategies being used to mitigate the risk of VDBs was fight against malaria campaign during construction of the Panama Canal from 1905 to 1909. There are some recent examples that are based on the experience from the Panama Canal. A comprehensive literature review established that existing efforts based on the use of built environment- related strategies to mitigate the risk of malaria are being driven from a public health perspective. The people who responsible for decision making during the design and construction of buildings are conspicuously missing from this conversation. This position was validated through a survey of East African-based built environment professionals.

The results of the survey also suggested that there is an interest among design professionals for more knowledge to be provided on the relationship between the built environment and the risk of VBDs such as malaria. More specifically, they expressed an interest in developing an understanding on the ways through which design decisions can be used to promote the realization of health outcomes such as malaria prevention. The author has outlined a conceptual architecture for a knowledge management platform that can be used to facilitate the required exchange of information. The proposed platform can also host training material and a checklist that can both be used to guide the design team on opportunities for mitigating the spread of VBDs during each stage of the construction life cycle.

The effectiveness and efficiency of the proposed knowledge management approach will predicate on the ease with which its intended target audience, designers of buildings, can access actionable insights. The development of the platform should therefore include the provision of an interface that can be used to push and pull actionable insights into existing design tools. An important distinction must be made here. The required educational and training material are intended for an audience that is based in a practice setting. The focus should be more on generating actionable insights.

Given the complexity of the problem that was illustrated through the analysis of the interlinkages and interdependencies of the source factors, there will be a need for the proposed knowledge platform to be linked to forums managed by agencies that have convening power. Examples include professional associations, government agencies, donor organizations as well as institutions that fund research. Some of the required educational and training needs can be addressed through embedding modules on the risk of VBDs into the course offerings for securing professional education credits.

In subsequent efforts, the users will be invited to provide input into the design of the next iteration of a conceptual architecture of the proposed knowledge management platform. This will be accomplished through a month-long field visit to Kenya. The Kenyan context exemplifies the linkages and interdependencies in the factors that propagate the risk of malaria infection. This risk is compounded by the fact that, as its population continues to grow rapidly, Kenya's urbanization rate is high, which in turn has increased the volume of construction. All these factors have propagated the risk of VBDs such as malaria. The local construction industry in Kenya is expected to have an annual growth of 6.2 % until 2026 (Nduire, 2017). The follow up activities will also include both surveying a large sample size of built environment professionals and hosting work meetings. The latter will be directed at improving the understanding of the unique educational and training needs of the different disciplines presented in this sector. There will also be semi-formal interviews with government officials in relevant sectors.

Appendix

A. 1 Built Environment Intervention Method - Screened Eave Tubes (SET)

	Built Environment Intervention Strategies
	Screened eave tubes (SET)
Built Environment Source Factors	
Artificial Breeding Sites	The mechanism of a SET requires a wall that separates an interior from an exterior. Though these tubes may not be used for breeding sites like drains, gutters, swimming pools, or tire tracks (De Silva and Marshall, 2012) placing a treated screen on these types of areas can open new, innovative solutions to preventing malaria in those sites, such as electrostatic coating (Okumu 2017)
Inlets/outlets for air transfer and ventilation	Eave tubes have been used to provide ventilation and thermal comfort in homes.
Urbanization	Due to the scalability of eaves tubes, there must be a focus on high-risk groups that serve as priority, before the intervention technologies are scaled to the entire community (Okumu 2017)
Poor housing material	There is strong correlation between the use of traditional building materials and techniques, and the prevalence of malaria (Tusting *et al* 2015).
More excavated areas causing open surface water bodies	Increased open surface water bodies cause more opportunities for malaria propagation.
Building envelope modifications (modifying size/placement of openings)	The specific size, orientation, and geometry of SET affects the accessibility of the home to the mosquitoes.
Global Health Source Factors	
Low standard of living (ex. socioeconomic status)	Low SES to the extent of homelessness within poverty may occur in urban regions. Poverty can result is the greatest risk factor towards malaria. Poverty reduces opportunities to a formal education, which reduces chances to get a good job, recycling into increased poverty. (Adefemi K et al 2015)
Insufficient GOV/NGO funding	Decreased funding from public or private groups may affect the scalability of SETs, lowering the amount of SETs that can be implemented.
Lack of health education (ex. hygiene practices, blood transfusion)	No relationship found
Lack of synergy among institutions/ organizations	No relationship found
Geographic residence (ex.	Malaria is transmitted by different *Anopheles* species, which can

urban, periurban, rural, river, coast, altitude)	vary by geographic environment. Some vectors are more dominant by density of location than others (Anopheles Mosquitoes). Therefore, more SETs should be implemented in regions with higher prevalence.
Urban agriculture practices	These practices cause an increase in breeding sites.
Antibiotic resistance	No relationship found
Climate Change Source Factors	
Changes in global wind pattern	Increased prevalence of the *Anopheles* vector will result, causing greater need for this intervention method.
Deforestation from land use	Deforestation increases prevalence of the malaria vector. Because buildings are made by initial deforestation, the increase in homes requiring SETs mirrors the increase in the deforestation.
Desertification and drought	No relationship found
Higher relative humidity	Increased relative humidity allows the vector to live longer, so an increase in the number of vectors would require more durable and longer-lasting screening materials.
Increased rainfall (precipitation)	The type of rainfall, the amount of rainfall, and the time of year of rainfall can affect the breeding of the vector. More durable screened eave tubes would be required for areas that breed more sites from precipitation.
Increased temperature	Temperature is directly related to the mosquito development life cycle. This means there will be a greater requirement for screened eave tubes
Pollution (poor indoor air quality)	Poor air quality results in a greater number of mosquitoes and less comfort for inhabitants

A. 2 Global Health Intervention Method - Artemisinin Combination Therapy (ACT)

	Global Health Intervention Strategies
	Artemisinin-based combination therapy drugs (ACT)
Built Environment Source Factors	
Artificial Breeding Sites	More larvae development results in greater mosquito population density, resulting in uneven distribution of therapy needed and greater number of individual at risk for disease.
Inlets/outlets for air transfer and ventilation	Poor outlets for air transfer result in less thermal comfort in the home. Inhabitants are driven outside, resulting in more cases of infection, and thus greater need for therapy.
Urbanization	Increased population means greater demand for this product.
Poor housing material	Poor housing material results in increased susceptibility to mosquito. Increased use of the drug can result in problems related to pregnancy.
More excavated areas causing open surface water bodies	Increased surface water bodies result In more opportunities for breeding. Greater infection requires more use of these drugs.
Building envelope modifications (modifying size/placement of openings)	Poor envelope modifications will result in more mosquito infections, increasing the demand for the drug in homes that cannot easily modify retrofits.
Global Health Source Factors	
Low standard of living (ex. socioeconomic status)	Because there are problems related to affordability and accessibility of this drug, those of low SES who already suffer the financial burden of disease treatment are further at risk.
Insufficient GOV/NGO funding	Insufficient cost for deploying treatment results in increased communities at risk for disease.
Lack of health education (ex. hygiene practices, blood transfusion)	Those unaware of malaria as a VBD may consider it as an ordinary fever and refuse to get treatment. They may also consider the root of the disease to be spiritual rather than medical, forcing behavioral changes over treatment (Adefemi K et al 2015).
Lack of synergy among institutions/ organizations	More costs being wasted among groups working in parallel. This results in less than the maximum potential for treating those at risk.
Geographic residence (ex. urban, periurban, rural, river, coast, altitude)	Those in regions where the species of *Anopheles* is more prevalent will increase the demand, resulting in a greater need for affordable and accessible therapy drugs.
Urban agriculture practices	This results in increased opportunities for reproduction of mosquitoes. Each generation can adapt to the therapy through antibiotic resistance, so more effort is needed to create a long-lasting therapy.
Antibiotic resistance	Antibiotic resistance from increased use of drug results in less effective therapy. Cost increases for institutions to discover and develop new drugs.

Climate Change Source Factors	
Changes in global wind pattern	Dispersal of the vector to different geographic regions result in greater need to outsource the drug to new communities, which results in difficulty for those unable to afford or access the drug.
Deforestation from land use	Deforestation results in pools of water exposed to sunlight (increaed temperature), ditches and puddles (larvae development), reduced absorption of water by forest environment (more standing water), and creation of "tree bowls" (stumps that collect pool water). This results in less effective natural prevention from malaria, causing increased need for drugs. (Austin 2017)
Desertification and drought	Increased prevalence of the *Anopheles* vector will result, causing greater need for SETs.
Higher relative humidity	Humidity and number of estimated cases are directly related (Li 2013), so the demand for therapy would increase.
Increased rainfall (precipitation)	Parasite density fluctuates according to monthly rainfall pattern, resulting in more malaria cases for adults and children (Odongo-Aginya 2005). This requires scientists and economists to match the demand of the drug with weather patterns, adding complexity to drug distribution.
Increased temperature	Temperature and number of estimated cases are directly related (Li 2013) (Lindblade 2000)
Pollution (poor indoor air quality)	Increased emission and dispersal of pollution results in greater personal exposure on average and by intensity, which can increase the incidence, duration, severity, and frequency of acute respiratory or acute lower respiratory infections. This influences the risk of malaria and other infectious diseases (Ezzati and Kammen 2002).

A. 3 Global Health Intervention Method - Insecticide treated bed-nets (ITN)

	Global Health Intervention Strategies
	Insecticide treated bed-nets (ITN)
Built Environment Source Factors	
Artificial Breeding Sites	No relationship found
Inlets/outlets for air transfer and ventilation	Increase in poorly designed inlets result in greater need for comfortable movement and ITNs.
Urbanization	Increase in population density results in greater demand for ITNs.
Poor housing material	Poor housing material results in greater vector accessibility in the home, increasing risk of infection.
More excavated areas causing open surface water bodies	No relationship found
Building envelope modifications (modifying size/placement of openings)	Increase in poorly designed building envelopes cause greater need for effective ITNs.
Global Health Source Factors	
Low standard of living (ex. socioeconomic status)	Decreased standard of living results in fewer inhabitants with ITNs, resulting in greater infection.
Insufficient GOV/NGO funding	Deploying less ITNs results in fewer residents able to use bed nets.
Lack of health education (ex. hygiene practices, blood transfusion)	No relationship found
Lack of synergy among institutions/ organizations	lack of synergy results in unequal distribution based of ITNs on risk of infection.
Geographic residence (ex. urban, periurban, rural, river, coast, altitude)	Some geographic areas have greater mosquito density, so the demand for ITNs trends with vector population.
Urban agriculture practices	Urban agriculture increases the opportunities for malaria vector growth and breeding, so more population density around an area results in greater need for ITNs.
Antibiotic resistance	No relationship found
Climate Change Source Factors	
Changes in global wind pattern	No relationship found
Deforestation from land use	No relationship found
Desertification and drought	No relationship found

Higher relative humidity	Longer living vectors require more durable bednets
Increased rainfall (precipitation)	More favorable habitat for reproduction. More generations of vector will result in antibiotic resistance to drug, resulting in less effective ACT drug.
Increased temperature	Faster mosquito development would result in greater need for bednets
Pollution (poor indoor air quality)	Pollution may increase the vector's attraction to the site, which would increase the number of bednets required.

A. 4 Global Health Intervention Method - Indoor Residual Sprays (IRS)

	Global Health Intervention Strategies
	Indoor residual sprays (IRS)
Built Environment Source Factors	
Artificial Breeding Sites	More indoor residual sprays would be needed for each breeding site created in the construction life cycle
Inlets/outlets for air transfer and ventilation	Air exchange features would increase the effect of residual sprays.
Urbanization	increased population trends similarly with greater need for indoor residual sprays
Poor housing material	poor housing material increases the vector attraction to the built environment, resulting in a greater need for indoor residual sprays within the home
More excavated areas causing open surface water bodies	More sprays would be needed to combat the increase in excavated areas that resulting in a greater mosquito population
Building envelope modifications (modifying size/placement of openings)	Poorly designed building envelope modifications result in greater need for sprays
Global Health Source Factors	
Low standard of living (ex. socioeconomic status)	Those of low SES may not be able to afford sprays, resulting in a malaria-prone environment both in and out of the home.
Insufficient GOV/NGO funding	lack of funding results in fewer residents who can use the sprays.
Lack of health education (ex. hygiene practices, blood transfusion)	Those unaware of malaria as a VBD may consider it as an ordinary fever and refuse to get treatment. They may also consider the root of the disease to be spiritual rather than medical, forcing behavioral changes over treatment (Adefemi K et al 2015).
Lack of synergy among institutions/ organizations	Lack of coordinated funding and advocacy results in less effective implementation strategies for intervention methods like sprays
Geographic residence (ex.	Population density differs based on the geographic location, so

urban, periurban, rural, river, coast, altitude)	there is a lessened effect on those physically living farther away or in population sparse areas
Urban agriculture practices	Because agriculture is an outdoor activity, there is no effect in the home.
Antibiotic resistance	Antibiotic resistance from increased use of spray results in less effective spray after generations of gene evolving. Cost increases for institutions to discover and develop new drugs.
Climate Change Source Factors	
Changes in global wind pattern	Increase in wind patterns result in greater spread of sprays, resulting in increased amount of resistance.
Deforestation from land use	increased open air for spraying results in greater spread, and lower likelihood of infection.
Desertification and drought	No relationship found
Higher relative humidity	Longer living vectors require more use of indoor residual sprays
Increased rainfall (precipitation)	This results in a more favorable habitat for reproduction, so more generations of vector will cause greater need for indoor sprays.
Increased temperature	Resistance spray molecules increase with temperature, causing greater area of spread per amount, reducing associated risk of malaria.
Pollution (poor indoor air quality)	Though spray produces a vector mitigating effect, the overall increase in atmospheric debris is higher.

A. 5 Global Health Intervention Method - Improved Sanitation Programs

	Global Health Intervention Strategies
	Improved sanitation programs
Built Environment Source Factors	
Artificial Breeding Sites	More sanitation programs needed to combat spread of disease from breeding sites
Inlets/outlets for air transfer and ventilation	Stronger intervention programs required when risk of disease increases due to this risk factor
Urbanization	Increased population causes more infrastructure requirements for formal teaching or training services.
Poor housing material	Poor housing material increases the opportunity for infection, requiring more education focused on the built environment.
More excavated areas causing open surface water bodies	Increased need for training centered on sanitation near built environment sites during phases of construction life cycle.
Building envelope modifications (modifying size/placement of openings)	Stronger intervention programs required when risk of disease increases due to this risk factor

Global Health Source Factors	
Low standard of living (ex. socioeconomic status)	Those in high risk areas may have a high povery risk, so includid sanitation programs may require focused effort on target populations, which requires greater funding
Insufficient GOV/NGO funding	Those in high risk areas may have a high povery risk, so includid sanitation programs may require focused effort on target populations, which requires greater funding
Lack of health education (ex. hygiene practices, blood transfusion)	Those unaware of malaria as a VBD may consider it as an ordinary fever and refuse to get treatment. They may also consider the root of the disease to be spiritual rather than medical, forcing behavioral changes over treatment (Adefemi K et al 2015).
Lack of synergy among institutions/ organizations	Lack of synergy would result in less effective strategies towards intervention, as less of those infected would be involved in the program than those that could be
Geographic residence (ex. urban, periurban, rural, river, coast, altitude)	Those in urban and peri-urban areas where there may be a higher risk due to built environment design and construction would have a greater need for sanitation programs, so those factors would propagate regardless of interventions.
Urban agriculture practices	No relationship found
Antibiotic resistance	More genetically evolving vectors would require more sanitation programs, as the programs themselves are more intervening than preventative.
Climate Change Source Factors	
Changes in global wind pattern	This increases the variety of species that have been to the same location, so improved sanitation may not particularly help a certain species because some respond more to lack of sanitation than others
Deforestation from land use	No relationship found
Desertification and drought	No relationship found
Higher relative humidity	Longer living species would require more sanitation programs to occur because the vectors would persist for longer than otherwise.
Increased rainfall (precipitation)	If the host is clean, then they have to fight off more infectious agents if the agents have more opportunities to breed.
Increased temperature	More favorable environments for mosquitoe development result in greater demand for sanitation programs.
Pollution (poor indoor air quality)	More pollution causes greater need for sanitation programs.

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Humanitarian Engineering & Social Entrepreneurship Aug 2016-Dec 2017
Department of Engineering Design
- Created social venture for brick firing/kiln development process in rural Tanzania
- Designed 20-day field work plan that was used to build/validate prototype abroad
- Developed stakeholder team using business models, VOC, and design thinking

Obonyo Impact at Scale Group May 2016-May 2018
Department of Engineering Design
- Developed humanitarian engineering-themed thesis study on built environment-related strategies for malaria control in urban Kenya/Tanzania
- Using engineering design and epidemiology principles to identify areas of opportunity for built environment-related malaria mitigation

Logan Microbial Fuel Cell Group Aug 2015-Dec 2015
Department of Environmental Engineering
- Comparing mesophilic and thermophilic electromethanogenesis using mini-MECs (microbial electrolysis cells)
- Observe methane and current generation from effluent in entirely anaerobic environment

PRESENTATIONS

Pareek, Sumit. (2017, September). *Using the design and construction of the built environment as a global health strategy for attaining scale and impact in the fight against malaria.* Poster presented at the **14th Annual International Conference on Urban Health, Coimbra, Portugal.**

Pareek, Sumit. (2017, April). *Pathways to impact at scale for malaria prevention: using the built environment as a global health strategy*, Poster presented at the **Penn State University Undergraduate Exhibition, University Park, Pennsylvania.**

Awards: Phi Kappa Phi Outstanding Research by a Junior - Physical Sciences & Engineering Category, Third Place in Information Literacy by Penn State Libraries

WORK EXPERIENCE

Process Quality Engineering Intern May 2017-Aug 2017
Stryker Medical Devices Flower Mound, TX

- Developed SOP & process improvements on surgical table rework
- Automated quality tracking system to reduce data entry time
- Redesigned production boards with senior management

Process Engineering Intern June 2016-Aug 2016
Air Liquide Advanced Materials Branchburg, NJ

- Diagnosed discrepancies in P&IDs, BOM, & plant installation
- Validated process documentation and interlock matrices

SERVICE

Co-Founder and President January 2016-February 2018
Student-Owned Learning University Park, PA

- Directed a cyber-tutoring program for underserved students for college readiness and diversity recruitment
- Lead application cycles, training sessions, advertising, and three mentor-student sessions per week
- Collaborate with university affiliate and high school staff for troubleshooting and grant funding

Summer Intern May 2015-Aug 2015
Einstein Healthcare Philadelphia, PA

- Conducted administrative and patient work with residents
- Exposure to internal medicine, ED, pathology, lab sciences, consulting, and cardiology (echo lab, CCU, telemetry) in urban setting

Summer Office Volunteer June 2008-Aug 2015
Lower Bucks Hospital Bristol, PA

- Exposure to Global Health & Travel Medicine, ER, and IT departments
- Recruited new clients for occupational injury insurance
- Maintained current client relations and reformatted client database

LEADERSHIP

International Conference on Urban Health	Poster delegate and society membership
Presidential Leadership Academy	Classes with university president/ SHC dean
Student-Owned Learning	Co-founder of cyber-tutoring club
India Currents Writer	Published articles on biculturalism
PSU Underground Writer	Student media site for diversity & inclusion
Schreyer Diversity Council	Minority in STEM representative
Global Engagement Leadership Experience	Intl./ Domestic harmony conference facilitator
Schreyer Honors Orientation	Three-day mentor to incoming students