

RAISING PORT ROYAL: A GEOSPATIAL RECONSTRUCTION OF THE 1692
CITY THROUGH INTEGRATED GIS AND 3D MODELING

A Thesis

by

CHELSEA MARIN COHEN

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	Filipe Castro
Committee Members,	Cecilia Smith
	Donny L. Hamilton
Head of Department,	Cynthia Werner

August 2017

Major Subject: Maritime Archaeology and Conservation

Copyright 2017 Chelsea M. Cohen

ABSTRACT

In 1692, the British port of Port Royal, Jamaica was largely lost to the sea after an earthquake shook the city down to the seabed, devastating the town and leaving the coastline of the peninsula permanently changed. Prior to its sinking, Port Royal was a town of some 6,500 people, a hub of shipping and commerce for the British West Indies, and a stronghold for British privateering in the Caribbean Sea.

After the earthquake, the peninsula on which Port Royal had been positioned was dramatically shrunk, and the major residential and economic centers of the city were lost to the water. This project endeavors to apply the archaeological information collected during excavations of the submerged city to a larger geospatial analysis of the area prior to sinking. The first portion of this project looks at using historical cartographic and archival data, along with contemporary bathymetry and satellite images to reconstruct the coast of peninsula supporting Port Royal in ESRI's ArcGIS software.

The second portion of this project focuses on the buildings excavated between 1981-1990, creating 3D digital models of the five buildings within the reconstruction of the Port Royal shoreline, and integrating them into the GIS model for comparative analysis. This is, to the researcher's knowledge, the first attempt to virtually reconstruct the structures of Port Royal based on archival and excavation data, and will allow for an interactive mechanism through which one can explore the structures of the excavated section of Port Royal in a scalable, geographically realistic way.

DEDICATION

To Albie – whose tireless company and relentless support saw me through the most trying of times.

ACKNOWLEDGEMENTS

I would first like to thank my committee chair, Dr. Castro, for his support and candor during this research process. It would not have been possible without his openness to incorporating new visualization methods into the archaeological field. Thanks also goes to Dr. Donny Hamilton, for allowing me access to the Port Royal files and his site data. The Port Royal field notes and archives supplied the majority of the information used in the building reconstructions, as well as the site plans and individual building plans used to create the geographic footprints. Moreover, his mentorship in historical archaeology and the Port Royal excavations made interpreting this data possible. Dr. Cecelia Smith has been an endless resource of information regarding GIS data and operations, and a beacon of encouragement when things seemed their most difficult. Thanks also to my peers and colleagues for being such an intelligent, exuberant, challenging group of people with whom to work. It has been an honor learning and working alongside you all. Finally, I cannot overstate how much the support of my mother and of Kyle Mingus have meant to me over the past two years. The two of you have pushed me to pursue my passion even when I felt as if I could not succeed. I would not be here without you.

TABLE OF CONTENTS

	Page
ABSTRACT	ii
DEDICATION	iii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	v
LIST OF FIGURES.....	vii
CHAPTER 1 INTRODUCTION	1
Methodology	3
CHAPTER 2 DEVELOPING A THEORETICAL FRAMEWORK FOR THE ARCHAEOLOGY OF PLACE.....	5
Delineating Space and Place in Archaeological Contexts	5
The Role of Place in Archaeological Reconstruction	7
Space and Place in the Port Royal Reconstructions	10
CHAPTER 3 A HISTORY OF PORT ROYAL	13
CHAPTER 4 MODELING THE PORT ROYAL SHORELINE IN A GIS.....	26
Hyper-Local GIS in Historical Archaeology	26
Reconstructing the Port Royal Shoreline	29
Reconstructing the Topographic Elevations of Old Port Royal.....	36
Extracting Z Coordinate Data	38
Problematizing the Shoreline Reconstruction	41
CHAPTER 5 SIMULATING THE STRUCTURES OF BUILDINGS 1-5	43
Domestic and Merchant Architecture in the 17 th -Century Port Royal	43
Port Royal and Bridgetown: Comparative 17th Century English Colonial Sites	48
Building 1	54
Building 2	59
Building 3	61
Building 4/5.....	64

CHAPTER 6 INTEGRATING 3D MODELS INTO A GIS	69
3D Modeling for GIS	69
3D GIS Applications in Archaeology	71
Integrating 3D Building Models within the Port Royal GIS.....	74
CHAPTER 7 VISIBILITY ANALYSIS OF A RECONSTRUCTED PORT ROYAL...	78
Visibility Analysis in Archaeological Reconstruction	78
Visibility Analysis among the Reconstructed Port Royal Buildings	83
Port Royal Skyline Analysis	88
Assessing the Skyline Tool Application	93
CHAPTER 8 CONCLUSION	94
REFERENCES	97
APPENDIX I GEOREFERENCED MAPS	106
APPENDIX II CONTOUR CREATION AND ELEVATION DATA	111
APPENDIX III RECONSTRUCTED BUILDING MODELS	119

LIST OF FIGURES

	Page
Figure 3.1: Excavated areas of Port Royal including the Marx and Hamilton excavations (Hamilton 2017).....	25
Figure 4.1: Port Royal prior to the 1692 earthquake, as depicted on a plate taken from the journal of seafarer Edward Barlow. Reproduced from the National Maritime Museum, Greenwich, London (Barlow, E.).....	30
Figure 4.2: 18 th -century plan of Port Royal and Kingston from La Biblioteca Nacional de España. Reproduced from La Biblioteca Nacional de España (Plano de Puerto Real en la Ysla Jamaica).	31
Figure 4.3: Revised shoreline map based on the 1981-1990 excavations georeferenced to a satellite imagery basemap of modern Port Royal	33
Figure 4.4: William Duke of Manchester-commissioned map georeferenced to a satellite imagery basemap of modern Port Royal	33
Figure 4.5: The reconstructed shoreline of pre-earthquake Port Royal (in yellow) overlaid on the basemap of the modern town.....	34
Figure 4.6: Georeferencing link table for the William Duke of Manchester map (top) and the shoreline map based on the 1981-1990 excavations (bottom).....	35
Figure 4.7: The old Port Royal shoreline as reconstructed in ArcScene (left) and Rhino (right)	40
Figure 5.1: Detail of map of London from 1580. Reproduced from the National Maritime Museum, Greenwich, London (Londinium Feracissimi An Gliae Regni Metropolis).....	49
Figure 5.2: Treswell, R., 1585, West-cheap (i.e., Cheapside), London. Reproduced from ARTstor Digital Library.	53
Figure 5.3: The reconstructed front of Building 1.....	58
Figure 5.4: Site plan for Building 1 as recorded by Hamilton and team (Hamilton 2017).....	58
Figure 5.5: Site plan for Building 2 as recorded by Hamilton and team (Hamilton 2017).....	60

Figure 5.6: The reconstructed front of Building 2.....	60
Figure 5.7: The reconstructed front of Building 3.....	63
Figure 5.8: Site plan for Building 3 as recorded by Hamilton and team (Hamilton 2017).....	63
Figure 5.9: The reconstructed front of Building 4/5	67
Figure 5.10: The reconstructed top of Building 4/5	68
Figure 5.11: Site plan for Building 4/5 as recorded by Hamilton and team (Hamilton 2017).....	68
Figure 6.1: Adjusting model position in ArcScene	74
Figure 6.2: The reconstructed structures overlaid on the 1981-1990 excavation map.....	76
Figure 6.3: The reconstructed shoreline with integrated building models	77
Figure 7.1: Binary viewsheds for building 1 (top left), building 2 (top right), building 3 (bottom left), and building 4 (bottom right). All visible area is represented in blue, and non-visible area represented in gray.	87
Figure 7.2: An overlay of all skyline horizons out to 5 km for building 1-5	89
Figure 7.3: The skyline (purple) generated from the top left window of Building 4/5 as seen from window level (top) and from above (bottom). The purple line depicts the line of obstruction to the horizon line (in blue). Facing the street, everything inward of the purple line depicts the visual obstructions from the observer point.	91
Figure 9.1: William Duke of Manchester Map	107
Figure 9.2: Revised shoreline map based on the 1981-1990 excavations (Hamilton 2017).....	108
Figure 9.3: 1683 map of Port Royal by William Hack of London’s Mapping School ..	109
Figure 9.4: Bathymetric data from submerged area of the old city (Hamilton 2017)....	110
Figure 9.5: DEM of southeastern Jamaica	112
Figure 9.6: Map depicting the DEM after being clipped to the Port Royal shoreline ...	113
Figure 9.7: Contour lines extracted from the DEM	114

Figure 9.8: Contour lines created from the bathymetric data of the submerged site	115
Figure 9.9: Fully integrated and smoothed contour data.....	116
Figure 9.10: TIN generated based on the contour data	117
Figure 9.11: The final DEM of old Port Royal based on the TIN data.....	118
Figure 9.12: Elevation of the Building 1 reconstruction.....	120
Figure 9.13: Perspective view of the front of Building 1 reconstruction.....	120
Figure 9.14: Overhead view of the Building 1 reconstruction.....	121
Figure 9.15: Elevation of the Building 2 reconstruction.....	121
Figure 9.16: Perspective view of the Building 2 reconstruction.....	122
Figure 9.17: Overhead view of the Building 2 reconstruction.....	122
Figure 9.18: Elevation of the Building 3 reconstruction.....	123
Figure 9.19: Perspective view of the Building 3 reconstruction.....	123
Figure 9.20: Overhead view of the Building 3 reconstruction.....	124
Figure 9.21: Elevation of the Building 4/5 reconstruction.....	124
Figure 9.22: Perspective view of the Building 4/5 reconstruction.....	125
Figure 9.23: Overhead view of the Building 4/5 reconstruction.....	125

CHAPTER 1

INTRODUCTION

Late morning on Saturday, June 7, 1692, was not much different than any other day in the colonial English city of Port Royal, Jamaica. The wharves along the harbor side of the city were packed full with merchant and navy ships, while in the city center people came and went from the market, warehouses, and stores that occupied most of the street level. Families and business colleagues, alike, were sitting down to tea as a slow, hot breeze swept over the small desert spit at the entrance of Kingston Harbor. The sky was clear. The city was filled with noise, the hurried footsteps of the urban populace, the chatter of thousands compacted into a space so small that not even hushed tones could keep personal matters truly private, the clatter of porcelain and pewter as patrons ate, drank, and made merry in the city's taverns and inns. It was a day as busy as any in the commercial heart of the Caribbean when the ground began to shift.

Earthquakes were nothing new in Jamaica, and often were laughed off among residents as those who had never experienced one before panicked at the shaking. At around 11:42 that Saturday, when the shaking began, Port Royal residents thought nothing of the tremors, though a loud moan from the very stone within mountains on the other side of the harbor caused some curiosity. The first shock passed with little concern. Quickly thereafter, the tremors began again, this time more violent, stopping only shortly to allow the thunderous roar of the third shock. Port Royal began to shake again

as it had never done before. Screams of horror, panic, and anguish filled the city as the sea began to rise around it on all sides. The waves rapidly became a secondary concern, though, as the ground turned to quicksand and began to swallow people and buildings whole. People clamored for higher ground as the commercial heart of the city was swallowed whole into the earth.

Even as the shaking continued, waves swept over the seawall, crashing violently into the city and carrying people out with them. On the harbor side, ships slipped from the moorings. Some were carried out to sea, while others were forced upon the land. One ship, *HMS Swan*, was pushed from where it was being careened into the roof of Lord Pike's residence with such force that it dislodged walls and settled completely on top of the building. Those swept away in the tide grasped frantically for the hull of *Swan*, and for those that could pull themselves in, the ship provided them with salvation from a panicked, horrendous death (Clifford 1993: 109).

In just minutes the city had succumbed to the sea, and when the shaking stopped, some two thirds of the physical land occupied by the city and an estimated three quarters of its population had been lost. The town, once connected to the rest of the island by a narrow strip of land, was now an island. Of the five forts that once protected the island, only Fort Charles remained. The church, the Governor's House, the market, and the wharves were all lost to the city. The buildings which were not submerged were largely still devastated, their bricks falling into heaps at their bases. Port Royal was devastated beyond repair, and despite centuries worth of effort, the area would never truly recover.

Archaeological excavation has endeavored to recover some of the missing city's structures, and an investigation led by the Institute of Nautical Archaeology (INA) in conjunction with the Texas A&M Nautical Archaeology Program and the Jamaican National Heritage Trust under the direction of Dr. Donny Hamilton between 1981 and 1990 uncovered five full structures, as well as several more partial excavations and the remains of ship crashed into a building. This thesis endeavors to apply the archaeological information collected during the Hamilton excavations to a reconstruction of the early Port Royal shoreline. Using a Geographic Information System (GIS), this project reconstructs the probable pre-earthquake landmass, and integrates 3D reconstructions of the Hamilton excavated buildings to begin the process of simulating the larger pre-earthquake city.

Methodology

Much of the reconstructive efforts were established with the premise of not using exclusive or proprietary data. The methodology proposed was created with the intention of outlining a process for digital reconstruction of a site excavated prior to the researcher's inquiry. In this case, the researcher did not have access to unpublished materials. This occurrence is undesirable but inevitable in archaeology, and though some unpublished information was made available during the research phases of this project, none was included in the final analysis.

The first portion of this project looks at using historical cartographic and archival data, along with contemporary bathymetric data and satellite images to reconstruct the

coast of the peninsula supporting Port Royal. Archaeological and geographical surveys of the area have established a basic reconstruction of the area's coastline prior to the earthquake. Georeferencing historical maps and extruding bathymetry of the now-submerged area will help refine these rough lines and create a more comprehensive understanding of the space in which Port Royal residents lived and worked.

The second portion of this thesis focuses on five buildings excavated by Hamilton, creating 3D digital models within the reconstruction of the Port Royal shoreline. This attempt to virtually reconstruct the structures of Port Royal based on archival and excavation data will allow for an interactive mechanism through which one can explore the structures of the excavated section of Port Royal in a scalable and geographically realistic way. This is significant not only to further our understanding of the finds from the Hamilton excavation, but also to bring integrated geospatial analysis and 3D reconstruction into the field of archaeology. Both of these objectives are currently considered individually within archaeology, but little has been done in the field to demonstrate how they may work together in a meaningful way for archaeological research using archaeological analysis.

CHAPTER 2
DEVELOPING A THEORETICAL FRAMEWORK FOR THE ARCHAEOLOGY
OF PLACE

Delineating Space and Place in Archaeological Contexts

Archaeology often deals with the intertwined concepts of space and place, but rarely do theoretical programs detail how archaeologists interact with and interpret these geographies. By design, archaeology both takes up and inextricably alters space, entering into the field to record the spatial context of artifacts and features, but also in many cases to move them and thus permanently alter the characteristics of the site geography, as well as the geography of the archaeological material (Wheatley 2004: 3). Better understanding of both site and material, though, is achieved in the context of the archaeological space and the historical place. Analyzing the two first necessitates a codified understanding of the differences and intersectionalities of space and place.

Space, at its core, can be considered the root geography in which anything occurs (Lowe 2009: 22). Space is physical but unembodied, and may have features but holds no inherent meaning. A geography or feature as it exists only in the physical sense and without any social value assigned to it occupies space (Rodman 1992: 641). Place, at its simplest, is space embodied. Place is created when value is assigned to space by those who know of and interact with the physical geographies (Rodman 1992: 641). Space is finite and cannot exist in multitudes at one point. An endless number of places, however,

may all coexist within a single space, each owing to different values and contexts assigned to a space by different people or people groups.

In archaeology, layers of place are often not only distinguishable but visible. In English archaeologist's Christopher Tilley's works on interpreting landscapes, he posits that there cannot be non-contextual definition of place (Tilley 2010: 27). By this account, place in archaeology may be altered by experience, and thus must be considered both in regards to individual experiences and the paths between them that can transition a sense of place (Tilley 2010). Place must accordingly be experienced, and through that experience a definition or value assigned in relation to the experience within the physical space. A conspicuous example comes from the Athenian Acropolis, which over the course of millennia went from being a Neolithic camp, to a fortified Mycenaean city, to a series of Hellenic and later Hellenistic citadels, to a Christian place of worship, to an Ottoman fortification, to a modern-day symbol of nationalism for the Greek state. In a single space, in this case a limestone hill overlooking a coastal Mediterranean basin, place was and continues to be constantly reinvented and refined, and given time, these major adjustments in the perceptions of embodied space often become visible in the material record.

What remains more difficult to trace in archaeology is simultaneous places within a space. A space may hold numerous place values at once, each one assigned by a different group. These divergent values are often conflated in the material record due to their temporal proximity, and cannot be easily parsed out through historical analysis (Low 2009: 24). Subsequently, interpretations of multiple forms of place often become

entangled and presented singularly, though sometimes with acknowledgement of variable values (Dell' Unto et al. 2016). Inconsistencies in place are seen as the trappings of space, an inherent characteristic of a geography to experience multiple meanings or be in use by multiple people, but all ultimately adding to extended knowledge of what is seen as a singular and concrete location (Harvey 2006: 121).

Thus, archaeology as a discipline is set up with the cross-purposes of examining space to understand place. Indeed, insofar as humans build and occupy space they nearly always create place by imbuing values, meanings, purposes, and memories onto the spaces that they hold. However, archaeological investigation is limited only to what exists within a space as the embodied place is often departed before investigation begins. Most archaeological research, though, seeks to understand place values through spatial context, creating a necessary link between the two that, in its best iterations, is based on both qualitative and quantitative analysis of the materials that may be indicative of the values once held within a geography (Wheatley 2004: 12).

The Role of Place in Archaeological Reconstruction

Due to its inherent connection to values, which can only be posited by archaeologists, place plays a contentious role in archaeological reconstruction. In an ideal situation place value decisions, such as aesthetic, are based on material remains and detailed archival records, but rarely does a site yield enough of these to allow a researcher to avoid place value estimations in reconstructions. For this reason, reconstructions must be viewed and should be presented as possibilities rather than facts

(Wells 2008: 5). Most archaeological reconstructions represent a simulation of what a site may have been, out of an incalculable number of possibilities varying from slightly similar to completely different, even while remaining in line with the physical evidence. During the process of reconstruction, a researcher must actively decide what place values will be represented in their simulation, from small details such as how sharp to make the turn of a corner to larger items including color of wall coverings and sometimes even the organization of a communal space (Wells 2008: 5). Place, then, often becomes a major if indirect consideration during archaeological reconstruction, with great attention paid to how place values should or should not be represented, and how decisions for those values may be substantiated.

Purpose of the reconstruction is a critical determiner in establishing how place values may be represented. The level of detail required of the reconstruction, in particular, dictates to a degree what types of place values should be represented (Gregory and Ell 2007: 89). Reconstruction of a building, for instance, could vary from an undetailed polygon representing where the structure stood to a fully detailed, textured model made as close to real-world images as possible, as well as a myriad of possible interpretations in between. At each level of increasing complexity, more place value decisions must be made, such as where to locate windows, how to cover walls, what form the interior of a structure took, and what was located within the building. That which is not directly provided for by material evidence then becomes the decision of the individual developing the reconstruction, and with every interpretation or creative choice, new place value is assigned to the space that may or may not have existed in an

earlier context (Gregory and Ell 2007: 109). If the reconstruction does not require great detail, it becomes easier to separate it from the extant data by incorporating physical attributes that delineate it from depictions of what was found at the site. Creating blocky or intentionally synthetic-looking models is perhaps the easiest means to avoid propagating newly generated place value in reconstruction, but the purpose of the reconstruction must allow for that lack of detail. If a life-like model is required, other means of clarifying interpreted place value must be established and made clear, or run the risk of decisions made on behalf of the simulation being interpreted as fact (Sheppard and Cizek 2009: 2104).

As critical as purpose, though, is scope of data, which encompasses not only field data but historical and archival research. Insofar as place values in reconstruction may be substantiated by the project's dataset, decisions regarding the reconstruction of place become less an artistic choice on behalf of the researcher and more a representation of the most probable amongst the many forms a place may take (Sheppard and Cizek 2009: 2107). When the data set cannot substantiate place values created within a reconstruction, the model as whole becomes more of an artistic endeavor than an exercise in anthropological probability. Unsubstantiated decision may be unavoidable depending upon the function of the reconstruction, but should be acknowledged and whenever possible should be discernable from both the raw site data and interpreted but substantiated data (von Schwerin, Richards-Rissetto, *et. al.* 2013: 749).

Distinguishing between the physical space, remains of the embodied space, and interpretation of place is necessary for the ethical treatment of archaeological

reconstruction. It helps to avoid misrepresentation in data, and incorporate an understanding of the single temporal place being depicted, though the physical space may have been imbued with a number of place values. It is with this overarching theory in mind that the Port Royal landmass and buildings were reconstructed.

Space and Place in the Port Royal Reconstructions

In reconstructing the Port Royal excavations, space and place have separate but not discrete duties. The reconstruction of Port Royal necessitates the reconstruction of space in that portions of a physical landmass were lost to the sea during the earthquake. With respect to this portion of the reconstruction, the objective is clear and concrete: create an approximation of the shoreline and elevations of the landmass as they may have been prior to the earthquake. The resulting model still represents a simulation and one of many permutations that a reconstruction could take. The raised landmass does not, however, require place value decision, as its generation is predicated entirely upon collected data rather than interpretation.

The building reconstructions necessarily interact with the spatial reconstruction of the shoreline, but present a greater challenge with regard to interpreting their place values. Finds within the structures, as well as the structural remains, themselves, help provide substantiation for some place values, but the upper portions of these structures, which would have been designed to fit specific desired functions, are no longer intact, and little archival data remains regarding Port Royal, itself, for the basis of the reconstruction, though inventory data allowed excavators to determine function room-

by-room. Recreating the upper portions of these buildings, then, required interpreting place value based upon what is known of British Caribbean urban architecture of the time, and each building model contains no small amount of estimation in analysis of its appearance and function. Interpretation of function, for its part, was made well before the start of the reconstruction by the excavating team and project directors, and the models make no effort to contradict nor expand upon the original interpretations of the structural functions.

Insofar as could be avoided, the models also make no effort to contribute unsubstantiated place value. The function of the GIS analysis requires no interior development, so the reconstruction represents only the outer structures. The footprints of the structures, as well as door placement, construction materials, and probable height are provided by the archaeological data, while archival research provided substantiation for that which was not represented through the archaeological data, and helped give form to building features including roofs and windows. Largely, the only presumed values in the models are the texture maps applied to the exterior. The textures represent likely materials based upon historical data, but are only scarcely supported through archaeological evidence. All exterior walls excepting Building 3 were given a brick texture, as they were known to be built of brick. Building 3, as a wood building, was given a wooden texture. All doors and window frames were presumed to be of wood, while the window lattices were made of wrought iron. Roofs were shingled with wooden shingles to align with iconographic depictions of other British urban spaces at the time.

In order to best represent simulated information, textures were created from seamless photomosaic across the faces of the models, creating a level of uniform repetition that did not take place in structures like those at Port Royal. Further, these textures were not extruded in 3D, and thus lay flat on the faces of the models, creating an intentionally synthetic, digital look. This helps distinguish any presumed values in the models, themselves, from the spatial data provided by the excavation drawings and reports, which outline the physical form of each building.

CHAPTER 3

A HISTORY OF PORT ROYAL

Port Royal maintains historical notoriety through its destruction, but for decades prior the colonial city was one of the most significant ports in the Caribbean and in the British world. What is now known as Port Royal was, in the days before conquest, a barren and sun-struck tombolo hanging off the southern edge of the island of Jamaica. The area around Port Royal, and the island as a whole, saw the arrival and eventual conquest at least one group of indigenous peoples before an Arawak-speaking people, the Taíno, arrived in the seventh to eighth centuries CE, migrating up from the Orinoco region in Venezuela (Allsworth-Jones 2008: 34). The Taíno referred to the larger area surrounding Port Royal as *Caguay*, an area from which the indigenous population was historically noted to stage fishing expeditions (Pawson and Buisseret 1975: 6). To date, no physical evidence of Taíno presence has been found at the area later turned into Port Royal (Pawson and Buisseret 1975: 6). Such evidence may appear as investigation of the area continues, but current historical records indicate that permanent settlement in the area were not established until after Spanish conquest (Pawson and Buisseret 1975: 6).

Situated some 150 km south of Cuba and just over 106 miles west by south west of Hispaniola, and measuring 80 km north to south at its longest and 235 km at its widest point, Jamaica was a small but strategic outpost in the Caribbean at the time of Spanish settlement (Allsworth-Jones 2008: 46). Initial Spanish contact with the island, though, was more serendipitous than it was strategic, as the first European in Jamaica was

Columbus, who happened across the island during his second voyage of exploration of the region in 1494. He was later stranded there on his last voyage in 1504 (Kritzler 2008: 13). Spain turned to permanently settling Jamaica in 1510 in hopes of finding gold and silver ore in the island's mountainsides. A lack of precious metals quickly turned Spanish attention to colonizing the island's interior under the premise that the colonists could enslave the local Taíno population to use as labor for large scale agricultural development. European disease and extensive, horrifying mistreatment of the captured natives rapidly decimated the native population though, leaving the island to serve as a sparsely populated supply outpost in between more prosperous settlements (Atkinson 2006: 163).

Spanish control of the area lasted for some 145 years, when back across the Atlantic, in the British Isles, Oliver Cromwell assumed control of what was then the Commonwealth of England, Scotland, and Ireland (Pestana 2017: 5). Seeking to weaken Catholic influence in the New World and to simultaneously deliver a blow to the Spanish monarchy's economic prosperity by interrupting trade in the Spanish Main, Cromwell put his "western design" strategy into motion. His plans were foiled by the Spanish crown during a failed British attack on Santo Domingo, the capital of Spanish Hispaniola, in early 1655. Ill-equipped to attempt another raid on a Spanish stronghold, Cromwell's men turned to the less populated and much less fortified southern coast of Jamaica (Pestana 2017: 117-138). Attacking the main settlement, a small village at Santiago de la Vega, later to be called Spanish Town, England quickly took the island. Spain made few attempts to reclaim it, giving up entirely by 1660 (Pestana 2017: 117-

138). Cromwell's' generals quickly departed the island after Spanish surrender, leaving their men behind to create fortification and settlement in the area. The English soldiers began building Passage Fort, also known as Fort Cromwell, on a sandy spit of land they called The Point, establishing England's first true settlement on the island (Pestana 2017: 215-247).

Cromwell campaigned desperately to get colonists from New England and around the New World to resettle in Jamaica, but population growth was slow under his reign (Pestana 2017: 117-138). It was not until after The Restoration began in 1660 that British colonists came to the area in substantial numbers. With Cromwell gone, the island's English population began to boom particularly in and around The Point. Under King Charles II, Fort Cromwell was renamed Fort Charles, The Point was renamed Port Royal, and Britain's largest colonial settlement in the New World started to take shape (Pawson and Buisseret 1975: 49).

The Point provided a strategic location for safely and quickly unloading and loading ships as it wrapped around a natural harbor, and its place guarding the entrance to both the island's safest docking spot and the mouth of two prominent rivers also made it an ideally situated point for defense (Pawson and Buisseret 1975: 50). In order to build and man the harbors and fortifications that would eventually attract colonists, though, the small group of early settlers first needed more men. Some were brought in from Nieves and other English settlements in the Caribbean, but to get a population that was willing to build and fight for the defiant city at the heart of a colony surrounded on

nearly all sides by Spain, the Governor of Jamaica turned his attention to another outpost of men set up on the outskirts of the Spanish empire.

Before complete Spanish conquest of Hispaniola, the island back country was inhabited by groups of runaway slaves and indentured servants, escaped sailors and prisoners, castaways, and other outcasts from colonial society who subsisted by poaching the feral pig populations and roasting them on wooden racks called *boucan*. The term, a Francophonic adaptation of the native Carib Indian term, gave way to calling the back-country men who survived on such racks the *buccaneers* (Martínez-Fernández 2015: 11). These men, eventually pushed out of Hispaniola and onto the small neighboring island of Tortuga, grew increasingly bitter toward the hostilities of Spain. They began to band together to form the Confederacy of the Brethren of the Coast, an outlaw group capturing Spanish ships and recruiting other outcasts as they sought vengeance against the Spanish crown (Martínez-Fernández 2015: 31-32). Operating only on the periphery of Spanish Empire, the buccaneers were nevertheless successful enough in their local provocations that by 1657 Jamaican Governor D'Oyley took notice. Through unknown means of communication, he began actively recruiting the Brethren to serve as naval protection against the Spanish under English letters of marque, which would make the buccaneers' actions against Spain both legal and profitable as they could sell their prizes directly in the marketplace of Port Royal (Martínez-Fernández 2015: 33). The answer to the call was explosive, and by the late 17th century, the clandestine seizure and trade from pirates and privateers made the city the wealthiest possession in English North America (Hamilton 2006: 14).

The prizes and plunders of the buccaneers, coupled with profits from their illicit trade with other nation's colonies when they were out at sea and the safe anchorage Port Royal offered to other merchant vessels brought a constant flow of capital into the city. The distance from Europe and the lag between the regular Spanish supply fleets from Spain, which serviced the New World colonies, meant that their smaller Caribbean settlements often waited for months at a time to receive necessary supplies from Iberian ports. To communicate with and supply the smaller Spanish coastal villages, a fleet of small ships called "coasters," each especially designed for its intended route and lightly armed as defense against Spanish control in the region, regularly plowed along Caribbean coasts (Trussell 2004: 37; Zahedieh 1986: 574). Among these vessels, a small but impactful number of foreign ships carried beverages and foods, arms, cloth and clothing, earthenware and cooking instruments, glass, tools, furniture and more from Europe and the English colonies to Jamaica, and from there operated an always welcome illegal trade with the Spanish Caribbean ports (Trussell 2004: 37). Human cargo was by far the most profitable product, though, as slaves smuggled into Spanish ports would receive a purchase price of whatever was to be charged in Port Royal, plus 35% interest (Zahedieh 1986: 591). Such practices were publicly condemned but privately condoned by the English colonial governorate, leading Port Royal to become a city dominated by pirates, privateers, and ill practicing merchants, leading to its nickname as "the wickedest city in the world" (Hamilton 2006: 13).

These practices brought large amounts of money into Port Royal, transforming the small stretch along the harbor from a defensive position and cargo port into a powerful

trade post. The economic viability of Port Royal grew such that by the time of the city's height, trade and agriculture had eclipsed plunder and piracy as the driving economic forces in the city. As the merchant population of Port Royal grew along with other English colonies in the New World, tolerance for the buccaneers and their rowdy ways quickly diminished such that only the most discrete activities were accepted (Hamilton 2006:15). The growing economic and geographic significance of Port Royal continued bringing wealth to the city, and with it more colonists interested in getting involved in some aspect of the area's profitable import and export arrangements. As relations improved amongst colonial powers, the English strengthened their role in an international trade still regionally dominated by Spain, and Port Royal continued to serve a hub for importing, exporting, re-exporting, outfitting, and supplying the English merchants in the New World (Pawson and Buisseret 1975: 90). The opportunities in Port Royal were so numerous that between 1669 and 1692, the city had gone from a reasonably sized settlement of 800 houses to 2,000 houses occupied by some 6,500 to 8,000 residents all on the 51-acre tombolo (Pawson and Buisseret 1975: 136; Hamilton 2006: 16). Eclipsed in some rights by larger and more powerful Spanish cities in the New World including the Caribbean port of Havana and the Lima on the Pacific coast, Port Royal nevertheless represented significant strides for the English as they attempted to establish their own power in the New World.

A wall had been erected around the city in order to defend it from attacks both natural and man-made, keeping out the water during Caribbean storms as much as it kept out enemy fire. Brick buildings stood three and four stories high, an uncommon sight in

the English Caribbean and almost anywhere outside of Boston and London at the time in the English world (Pawson and Buisseret 1975: 136; Hamilton 2006: 16). By 1692, Port Royal was the largest British commercial port in the New World, as well as the most densely populated, rivaling any European city up to that point. In 1688, alone, 213 ships docked at Port Royal with a total tonnage of ships arriving in the harbor exceeding 9,000 tons (Pawson and Buisseret 1975: 87-91; Zahedieh 1986: 570). By comparison, during the same year 226 ships combined were recorded at all the ports of New England, and the total ship tonnage arriving in all of Britain's North American colonies was around 2,500 tons (Pawson and Buisseret 1974: 88, Trussell 2004: 39). For a brief time, Port Royal was the largest and most important city in the British New World.

Port Royal was still the hub of the British Caribbean on the morning of 7 June 1692. The harbor and quays were so overburdened with ships that fifth-rate military vessel *HMS Swan* was being careened in a merchant wharf due to lack of available space for outfitting military craft (Clifford 1993: 109). There was no sign of a hurricane or a great storm on the horizon, no indicator that the harbor might come under Spanish fire that day. At 11:45 in the morning, Port Royal was struck not by weather nor by fire, but by a small tectonic shift that would have a lasting impact.

Still centuries off from the theory of continental drift and a scientific understanding of plate tectonics, what the British, Spanish, and Taíno had no way of knowing when they settled the island was how Jamaica was formed, and exactly what its combined geography and geology meant for settlement (Pipkin, Trent, Hazlett, and Bierman 2010: 73). Situated on a boundary between the Caribbean Plate and the Gonâve

Microplate, Jamaica was formed when a restraining bend linking the two plates together came under tension and created an uplift that gave the island its mountainous topography (Pipkin, Trent, Hazlett, and Bierman 2010: 86). While other, smaller tectonic shifts almost certainly occurred during the days of the island's occupation, nothing was large enough to warrant thorough documentation by the Spanish or British until mounting tension along the plates forming the island finally gave way that day in 1692 in the east of the island, shaking the whole of the island from east to west (Mulcahy 2008: 401). Reaching what was later thought to be a 7.5 or higher magnitude, the quake traveled quickly and brought powerful shaking to the shores of Port Royal almost the instant it happened (Mulcahy 2008: 404).

Emmanuel Heath, Port Royal resident and the Reverend of St. Paul's Church, recalls the day of the earthquake not long after it happened in a series of two letters. Not long after sitting down with companion John White at a nearby tavern, Heath recounts the moment the earth began to move:

But to return to the President, and his Pipe of Tobacco. Before that was out, I found the Ground rowling and moving under my Feet, upon which I said, Lord, Sir, what's this? He replied very composedly, being a very grave Man, it is an Earthquake, be not afraid, it will soon be over: but it increased, and we heard the Church and Tower fall; upon which, we ran to save ourselves. I quickly lost him, and made towards Morgan's Fort, which being a wide open Place, I thought to be there securest from the falling Houses : But as I made toward it, I

saw the Earth open and swallow-up a Multitude of People, and the Sea mounting-in upon us over the Fortifications. (Rev. Heath 1692).

Immediate shaking caused the periphery of the town to fall into the ocean and crumbled the tall building lining Port Royal's streets, but the primary damaging factor wasn't the impact the seismic waves had on the buildings but what they did to the ground underneath. Through a process called liquefaction whereby loose, water-saturated soil is put under enough stress to cause the soil lose strength and behave like a liquid, the sandy bottom of Port Royal started to act like quicksand (Mulcahy 2008: 404). Buildings sank and slid off their foundations, with many around the edge of the city sliding into Kingston Harbor or sinking vertically into the sand with minimal horizontal disturbance. Those in the center of the city were not swallowed by the harbor, but instead stood in different states of disrepair or simply fell over due to the violent tremors (Pawson and Buisseret 1975: 166). Immediately following the shocks of the quake, a tidal wave ripped across the spit. The combined effects of the liquefaction saw two thirds of the city overcome by water, including the narrow strait of land that connected Port Royal to the larger island (Hamilton 2005: 167).

As the wave dislodged the city, so to was *HMS Swan* thrown from careening into the town, crashing through the roof of a building situated at the intersections of Queen Street and Lime Street (Clifford 1993: 109). American treasure hunter Robert Marx, who excavated portions of the city in the 1960's, found the remains a shipwreck he believed to be *HMS Swan*. However, the wreck found lying over the remains of a building on

Queen Street is a far more likely candidate for the naval ship, as according to English Historian John Oldmixon in his 1741 history of the Jamaican colony:

Among the rest a Man of War, the Swan Frigat, that lay by the Wharf to careen. The violent Motion of the Sea, and sinking of the Wharf, forc'd her over the top of many Houses, and passing by that where a Person call'd my Lord Pike liv'd, part of it fell upon her, and beat in her Round-house; she did not over-set, but help'd some Hundred in saving their Lives. (Oldmixon 1741: 324).

When the final impact of the 1692 earthquake was later assessed, an estimated 2,000 of the city's residents were killed during the quake and the tidal wave actions, with another 3,000 dying in the coming weeks due to starvation, lack of clean water, and the proliferation of disease that followed (Hamilton 2005: 167). The Port Royal landmass was reduced to some 25 acres (Trussell 2004: 41; Pawson and Buisseret 1974: 123).

The majority of those who survived fled the city in favor of safer harbor on the mainland, but not long after the quake government officials such as the receiver general and port officers were ordered back to work, and the trade network once again started to cautiously land ships in Kingston Harbor (Pawson and Buisseret 1974: 175). Port Royal would barely see the 18th century, though, as a fire broke out on 9 January 1703. It spread quickly, pushed along by the large stores of gunpowder kept at various points in the city and the tightly packed buildings which made it easy for flames to hop from one to the next (Johnson 2000: 46). In less than a day the remaining portions of the city were burnt to the ground. The aftermath of the fire brought a bill proposing shifting shipping and commerce across the harbor to Kingston. This measure was supported by merchants

but opposed by sailors who claimed the area would be too difficult for them to reach in their ships. The split caused the bill to be rescinded in favor of a plan that would let the two cities develop independently (Waters 2006: 5). Port Royal could not compete with the more soundly located Kingston, though, as a series of hurricanes in 1722, 1726, and 1744 repeatedly decimated the city (Johnson 2000: 48). Suffering from the constant damage the remaining commercial holdouts in Port Royal made their way to Kingston, and the once powerful city became a shelter for naval fleets and the Caribbean hub for the British Royal Navy (Pawson and Buisseret 1974: 173-204).

Eventually, the water receded and the spit connecting Port Royal to the rest of Jamaica re-emerged from the sea. British Naval operations continued in the area until 1905. By 1770, the naval dockyard was properly equipped to outfit large naval ships for trans-Atlantic voyages. By 1815, a new careening wharf was built south of the existing dockyard (Pawson and Buisseret 1974: 184). Meanwhile, administrative functions moved back to the colony's capital in Spanish Town, and by 1716 Kingston had become the largest town in Jamaica. On 14 January 1907, two years after British activity on the tombolo ceased, another earthquake again liquefied the soil under the city, destroying much of the rebuilt area and again altering the coastline (Waters 2006: 5).

As of 2016, little of the original Port Royal stands. The town that occupies the area now is a sleepy fishing village of less than 4,000 residents. Some efforts have been made to spark interest in the area through historical tourism, but few have gained traction due in part to so little of the old city remaining above the water (Waters 2006). The modern coastline of the city is markedly different from the way it would have

looked in the 17th century, and Port Royal has yet to be able to build up the population, wealth, or infrastructure that it had in the days before the earthquake. The submerged areas of the city were neither forgotten nor undisturbed in the years after the earthquake, but documentation of the area did not begin until underwater archaeologists started searching the area in the 1950s (Hamilton 2006: 49). Between 1981 and 1990, researchers with the Institute of Nautical Archaeology, Texas A&M University, and the Jamaican National Heritage Trust began excavations on a submerged portion of the city on the northeastern side of the tombolo (Hamilton 2006: 50). During these excavations, five building structures and one ship were recorded and analyzed, along with a bevy of artefactual data including glass bottles, red clay and kaolin clay pipes, pewter wares, porcelain, stoneware, and number of daily life and household items (Figure 2.2).

EXCAVATED AREAS
of
OLD PORT ROYAL, JAMAICA

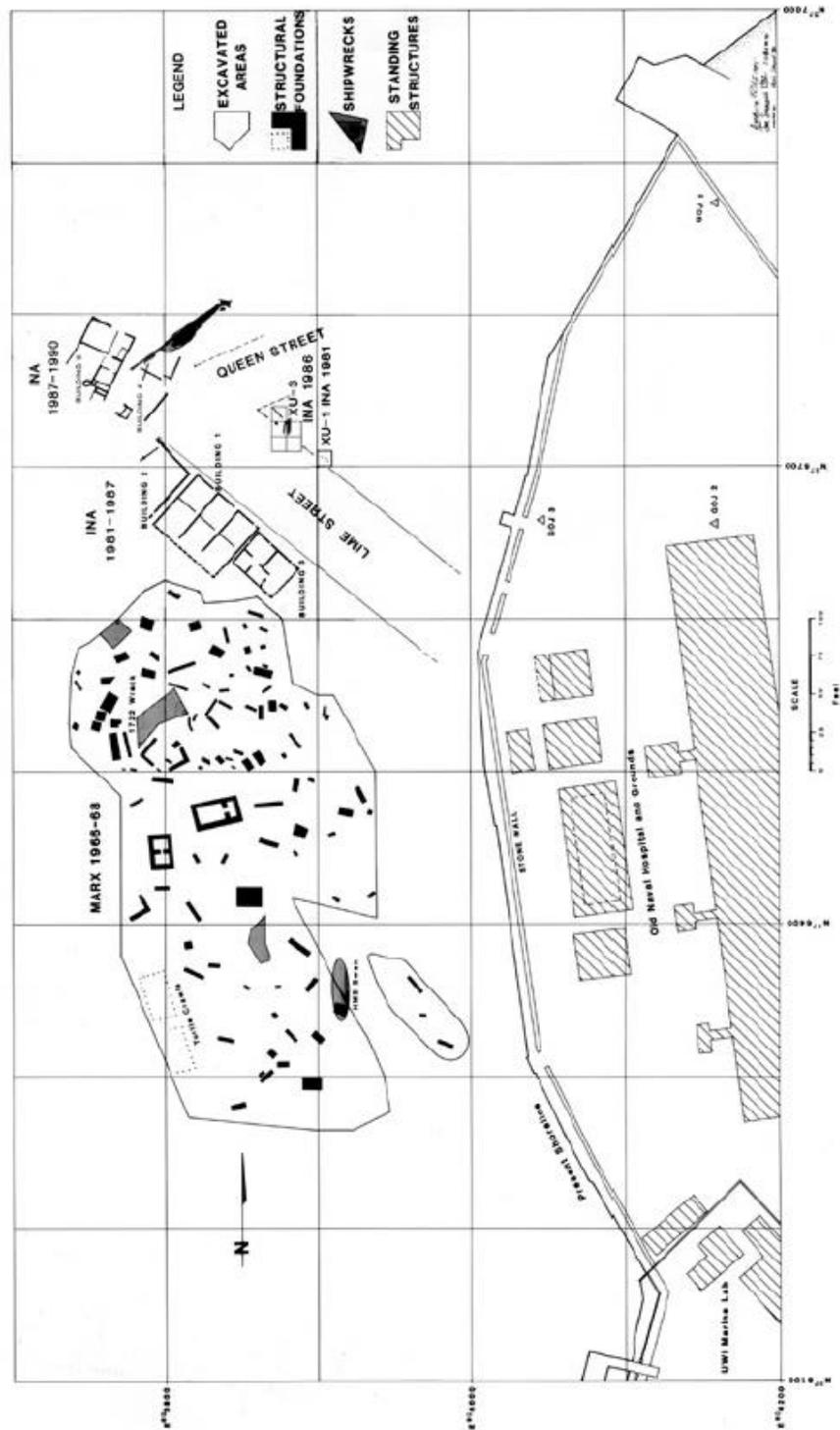


Figure 3.1: Excavated areas of Port Royal including the Marx and Hamilton excavations (Hamilton 2017).

CHAPTER 4

MODELING THE PORT ROYAL SHORELINE IN A GIS

When Port Royal, Jamaica, fell to an earthquake in 1692, the composition of the city was forever altered. An estimated two thirds of the city's land collapsed into the sea, leaving the landscape of the peninsula completely changed. The northern part of the peninsula was gone, and sediment never resettled in the area to rebuild the surface. With much of the physical landmass that was the old city of Port Royal gone, visualizing and analyzing archaeological data from the 1981-1990 Port Royal excavations was met with the challenge of representing land-based material that could only be projected onto the sea. In order to compensate for this and allow for better spatial analysis, a GIS was developed with the intent to project the elevations of the reconstructed shoreline in 3D, thus providing a potential rendering of what the old city's landmass may have looked like, as well as allowing for more comprehensive spatial analysis. Using small-scale, publicly accessible geographic data, the Port Royal reconstruction endeavored to provide a methodology for broadly accessible topographic reconstruction methods of local and hyper-local archaeological data.

Hyper-Local GIS in Historical Archaeology

GIS in archaeology has long served two functions. Its first function has always been as a recording tool, allowing archaeologists to map and store data gathered in the field, both in real time and after the field work is completed (Wheatley and Gillings

2002: 16). In this sense, the archaeological applications of GIS are inherently locally-oriented. Creating a GIS allows archaeologists to create a georeferenced database of composite artifact and feature information particular to the site of investigation (Wheatley and Gillings 2002: 16-18). As a recording tool, GIS works well locally, allowing for millimeter accuracy in recording and large quantities of data different types of data including locational, topographic, and diagnostic information to be stored in the same place (Brimicombe 2003: 52).

The second function of a GIS in archaeology is that of an analytical tool. Broadly grouped, GIS functions useful to archaeologists serve to either compare specific variables within a single site, or compare patterns across multiple sites. Examples of the former include examining the density of artifact distribution within a site or patterning proximity of defined artifact categories to features such as buildings or natural resources (McCoy, Ladefoged 2009: 272). Examples of the latter may include comparative distribution analyses for a predefined artifact or feature type, or spatial interpolation between multiple site (McCoy, Ladefoged 2009: 272). Both are useful tools for archaeologists, each with their own benefits and complications, but local analysis represents a unique challenge for the archaeological community.

A GIS easily handles the recording and storing of local data in a vector format, such those sitemaps commonly produced as parts of field reports and site publications. It does not, however, lend itself to easily bringing in local raster imagery for visualizations or raster-based analyses. This is largely because researchers create the vector attributes directly in a GIS. Direct generation allows a researcher to import data to their own

standards and specifications, while working in vector ensures that there are no issues with scaling or image resolution (Savisky, Lacher 2013: 45). Raster data, such as elevation models, satellite imagery, converted LiDAR data, or orthophotos of a site, are generated external to the GIS, and are thus limited by its resolution and stored image data quality (Savisky, Lacher 2013: 45).

This type of raster data is often helpful in reconstructing and visualizing the site, particularly when recording changes over different field seasons or phases of excavations. However, in most of the extremely local areas in which archaeological investigations often occur, regional and global data resolution is often not high enough to properly fit the intended design of a local GIS (Tomlinson 2013: 76). While some regions have well-funded geographic data gathering and distribution protocols, either through the local government or private investment, many other regions do not, including highly impoverished nations and areas struggling with ongoing violence or civil unrest. This leaves archaeologists with two options: either find funding and tools to acquire the necessary raster data for themselves, a process which is often time-consuming and expensive, or adapt the global data to fit their needs.

The old Port Royal excavation site offers an unparalleled opportunity to see how global data can be manipulated to fit a hyper-local site. At 51 acres total, the old city represents an incredibly compact site that does not easily register with global geographic data, and Jamaica has no current department or system setup to record, gather, or distribute island-specific geographic data. As no excavation team intentionally acquired

or developed raster data for the areas surrounding Port Royal, global data becomes the only real option to recreate an elevation model of the pre-1692 earthquake terrain.

Reconstructing the Port Royal Shoreline

The recurring decimation to the Port Royal area created a distinct challenge in reconstructing the shoreline of the sandbar as it was 1692. While sub bottom profiling may one day offer some options to create a more refined 1692 shoreline, available information regarding the seafloor composition of Kingston Harbor was not such that a set of lines marking the old shoreline could be extracted. Instead, a series of historical maps were georeferenced in ArcGIS 10 and overlaid to create a refined set of lines as a suggestion of what the shoreline may have looked like in 1692.

Geoprocessing began with a satellite image basemap by which known features on the historical maps could be georeferenced and assigned longitudinal and latitudinal coordinates. By assigning map locations values in a Geographic Coordinate System (GCS), those same coordinates would be visually projected into a two-dimensional space as part of a Projected Coordinate System (PCS) (Ormsby 2008: 335). Aligning multiple points within each given map allows the historical data to be projected across the base map image such that it reflects how the map should conform to the known existent physical area (Hill 2006: 2). As these maps are projected, ArcMap assigns them a certain form of transformation so that the data is properly calculated and projected to fit the type of space represented (Hill 2006: 80).

For the Port Royal shoreline reconstruction, four historical maps were used to create the refined shore edge. As the 1692 earthquake took with it a large portion of the Colony of Jamaica's official records, that which did not have duplicates in London or another public record office were lost to the sea (Pawson and Buisseret 1975: xiii). Excepting naval charts and individual structure plats, cartography of the area was not something likely to be sent to London, and so limited amounts of historical cartography predating the earthquake exist today in the public record. Those that do exist are more illustrative than navigational aids (Figure 4.1, Figure 4.2). Subsequently, the primary data sources for the shoreline reconstruction date to after the earthquake. Their date leaves greater room for error, as such maps are reconstructions unto themselves, but they offer the most reliable sources available to date.



Figure 4.1: Port Royal prior to the 1692 earthquake, as depicted on a plate taken from the journal of seafarer Edward Barlow. Reproduced from the National Maritime Museum, Greenwich, London (Barlow, E.)

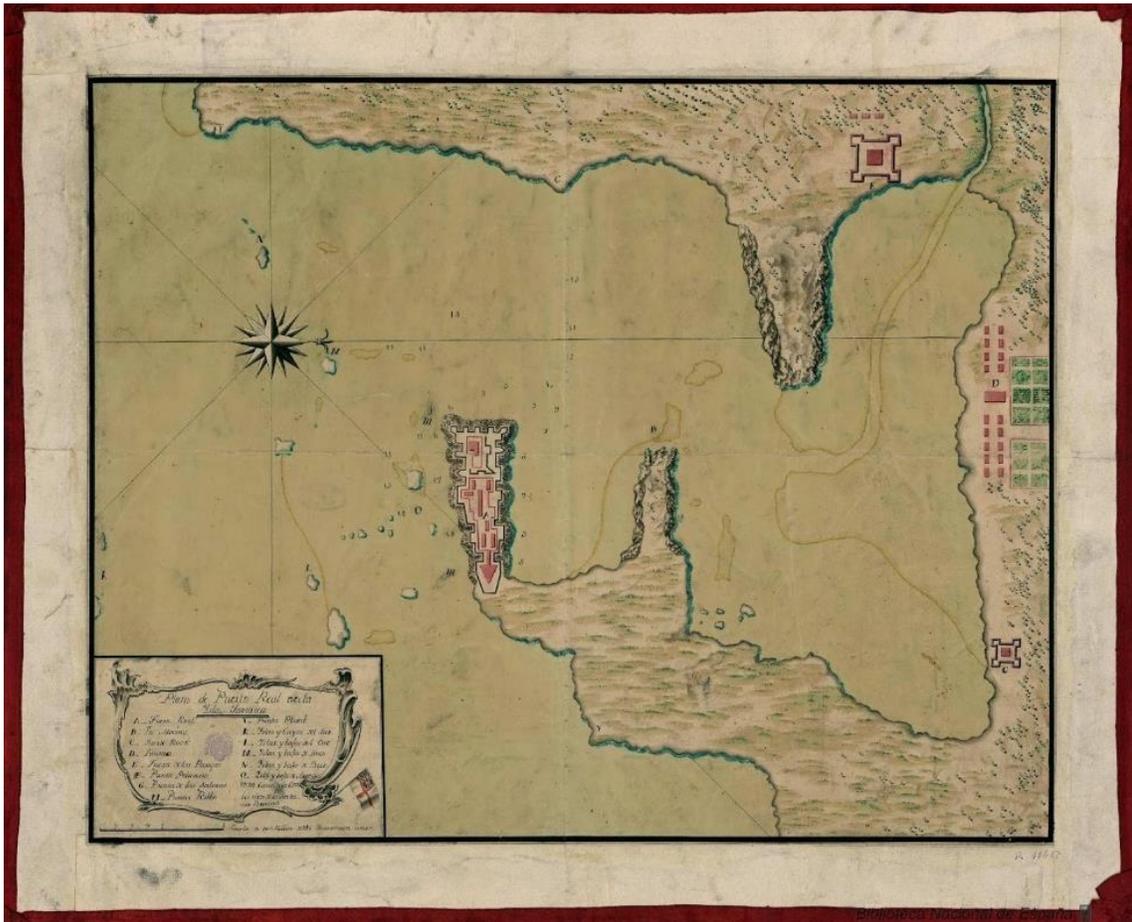


Figure 4.2: 18th-century plan of Port Royal and Kingston from La Biblioteca Nacional de España. Reproduced from La Biblioteca Nacional de España (Plano de Puerto Real en la Ysla Jamaica).

Among the four maps georeferenced, two in particular gave the shoreline its shape. The first, a map ordered by William Duke of Manchester and surveyed in 1827 by Phillip A. Morris to show the pre- and post-earthquake extents of the city, came from the British National Archives (MFQ 1/931). Manchester's map included an overlay of a 1680s-planning map, the original now lost, showing the street plan and shoreline of pre-earthquake Port Royal. This map, in many ways, provides the best structural reference for the Port Royal coast, as the overlaid planning map necessitates it holding as true to the scaled dimensions of the city as possible (Yang, Snyder, Tobler 2000: 61). Control points were placed along three structures at the Naval hospital, at opposite ends of St. Paul's church, on both ends of Fort Charles, and at the fire station to align the historical map with the base map (Figure 4.3). The second crucial map for reforming the shoreline was the revised shoreline map from the 1981-1990 excavations. This piece considered the seismic impact of where the shoreline slid versus where it sank directly into the seabed (Hamilton 2008: 265). As the revised map included a number of modern as well as historical structures, more control points could be added to it to allow for greater accuracy. Control points included the University of the West Indies laboratory building, St. Paul's church, the main building and one ancillary structure from the Naval hospital, two structures within the government housing complex, and street corners from the modern road plan for the north end of the peninsula (Figure 4.4).



Figure 4.3: Revised shoreline map based on the 1981-1990 excavations georeferenced to a satellite imagery basemap of modern Port Royal



Figure 4.4: William Duke of Manchester-commissioned map georeferenced to a satellite imagery basemap of modern Port Royal

As Port Royal is a hyper-localized space, the projection for the Port Royal historical maps needed above all to preserve the area represented. While the shape was mutable and in fact expected to change somewhat as each map was referenced, the overall area represented by each map was critical to establishing a refined set of shoreline plans. The transformation of each map, then, was decided largely to avoid distortion that may be created by pulling the map at a curve in reference to its datum. Subsequently, the four historical maps referenced to recreate the shoreline were assigned a spline transformation. The spline transformation allowed for maximum local accuracy and preservation of area by aligning each data point on the historical map exactly to its source data point on the base map, rather than pulling it close to the source data point as it would relate to a larger global curve (Pacina, Novak, Weiss 2011: 3). This created a smooth set of maps optimized for the Port Royal area, as the landmass is so small it has no need to correct for a 3D curve in two dimensional projections.



Figure 4.5: The reconstructed shoreline of pre-earthquake Port Royal (in yellow) overlaid on the basemap of the modern town

Link

Total RMS Error: Forward:0

Link	X Source	Y Source	X Map	Y Map	Residual_x	Residual_y	Residual
<input checked="" type="checkbox"/> 1	1173.235678	-2342.171231	-8554086.283...	2029920.519608	0	0	0
<input checked="" type="checkbox"/> 2	1363.206891	-1596.573906	-8553929.756...	2030189.230979	0	0	0
<input checked="" type="checkbox"/> 3	1247.982363	-1990.533416	-8554000.790...	2030052.580028	0	0	0
<input checked="" type="checkbox"/> 4	1129.688979	-1322.464385	-8553992.502...	2030338.204923	0	0	0
<input checked="" type="checkbox"/> 5	784.571437	-1443.394172	-8554149.135...	2030317.567381	0	0	0
<input checked="" type="checkbox"/> 6	981.658056	-2136.695673	-8554139.805...	2030011.510541	0	0	0
<input checked="" type="checkbox"/> 7	1292.252336	-2142.037698	-8554009.071...	2029980.396980	0	0	0
<input checked="" type="checkbox"/> 8	928.468449	-1697.744626	-8554111.546...	2030201.331813	0	0	0
<input checked="" type="checkbox"/> 9	1327.139865	-1618.664100	-8553945.131...	2030183.348745	0	0	0
<input checked="" type="checkbox"/> 10	1168.809465	-1328.288186	-8553978.813...	2030329.782298	0	0	0

Auto Adjust Transformation: Spline
 Degrees Minutes Seconds Forward Residual Unit : Unknown

Link

Total RMS Error: Forward:0

Link	X Source	Y Source	X Map	Y Map	Residual_x	Residual_y	Residual
<input checked="" type="checkbox"/> 1	2118.530110	-968.747542	-8554086.957...	2029919.253333	0	0	0
<input checked="" type="checkbox"/> 2	2204.652157	-1060.822726	-8554123.469...	2029957.750285	0	0	0
<input checked="" type="checkbox"/> 3	2208.280104	-1810.246613	-8554129.303...	2030318.633967	0	0	0
<input checked="" type="checkbox"/> 4	1818.654306	-1546.470865	-8553941.184...	2030196.263930	0	0	0
<input checked="" type="checkbox"/> 5	1360.628802	-1983.778676	-8553723.564...	2030408.592480	0	0	0
<input checked="" type="checkbox"/> 6	1029.434329	-2285.330245	-8553563.491...	2030552.790685	0	0	0
<input checked="" type="checkbox"/> 7	1480.423250	-1257.505851	-8553779.788...	2030055.373023	0	0	0
<input checked="" type="checkbox"/> 8	2215.313565	-1529.600440	-8554139.622...	2030189.649334	0	0	0
<input checked="" type="checkbox"/> 9	1602.435605	-1063.124718	-8553840.113...	2029961.710336	0	0	0
<input checked="" type="checkbox"/> 10	2276.625006	-544.526496	-8554230.110...	2029725.701531	0	0	0
<input checked="" type="checkbox"/> 11	2228.383633	-1969.636532	-8554138.035...	2030398.802877	0	0	0

Auto Adjust Transformation: Spline
 Degrees Minutes Seconds Forward Residual Unit : Unknown

Figure 4.6: Georeferencing link table for the William Duke of Manchester map (top) and the shoreline map based on the 1981-1990 excavations (bottom)

Reconstructing the Topographic Elevations of Old Port Royal

After reconstructing the shoreline, the next step in simulating the potential topography of old Port Royal was to extract elevations for the extant land and simulate a contour for the now submerged area. To extract the elevations, an ASTER Global Digital Elevation Model (ASTER GDEM) with a resolution of 1 arc-second was used. The digital elevation model (DEM) was loaded into ArcMap and clipped to the historical Port Royal shoreline (Appendix II, Figure 9.6). Clipping the DEM not only constrained the raster to the extent of the area of study, but made more evident the variation in extant Port Royal's elevation. However, with a 1 arc-second resolution, the DEM did not generate a clean elevation of Port Royal. Instead, it produced 40 individual pixels' worth of data across 51-acre area (Appendix II, Figure 9.6). Each pixel represented the highest point within the 1 arc-second grid, but the elevation data representing the change between pixels was unknown due to the data resolution (Appendix II). To rectify this, contours were extracted in ArcMap with a contour interval of 0.25 meters and a base contour of zero (Maunder 1999). This allowed the software to project predicted contours of 0.25 m elevation changes across the elevation data extracted from the DEM (Appendix II, Figure 9.7). This provided a dense enough set of contours to create a new set of elevation data for most of the old city. Contours were created only within the confines of the old city rather than across a larger area as Jamaica shows rapid elevation increases outside the Palisadoes, and the relatively flat elevation of Port Royal would have been quickly diminished. However, the impact of larger area contouring may be a challenge to address in future analysis. As the contours were based on the pixelated data,

the contour lines were first projected with hard turns and blocky shapes, so the lines were smoothed in ArcMap using the Bezier interpolation method. This created a Bezier curve for each contour that allows for scaling while maintaining the mathematical constant of the curve (Pal 2013: 3). The Bezier interpolation was favored over a Polynomial Approximation with Exponential Kernel (PAEK). Although a PAEK would have held true to the original extent of the contour's angles, the Bezier curves hold closer to the natural distribution of pixels with different elevation values. This also allows the curves to be scaled indefinitely, rather than settings a fixed number of vertices, resulting in the potential for blocky curves to reappear at smaller scales.

The smoothed contours provided the necessary elevation data for the parts of the old city that correspond with the current extent of Port Royal. To recreate the full elevation of the shoreline, contours needed to be projected in the area of the old city now covered by water. To this end, bathymetric data for the area on the north side of the peninsula was used to give a rough set of contours. The recorded bathymetry may or may not have been altered by the 1907 earthquake, but the area covered by the bathymetry data would have represented less than 2 meter of elevation change on the old shoreline, with no pre-earthquake iconography suggesting that the area had any notable high points as it was thought to come down at a rather steep slope (Pawson and Buisseret 1975: 3). The bathymetry curves were thus used as a rough guide to show the elevation changes of the shoreline. Each curve was presumed to represent a 0.25 m change, roughly corresponding to the depicted depth change on the bathymetric chart (Appendix II, Figure 9.8). Those curves that ran directly to the modern shoreline on the northeastern

side of the peninsula were refined to follow the curve pattern of the shore-side contour lines, creating a consistent slope from the modern shoreline down the lost shore to the harbor (Appendix II, Figure 8.9). Once the bathymetry curves were digitized, they too were smoothed using the Bezier interpolation method, and assigned elevation data following the 0.25-meter pattern of change. The curves derived from the bathymetry were then merged into a single polyline shapefile.

Once the contour map of old Port Royal was completed, it became possible to create a triangulated irregular network (TIN) to fill in the space between contour lines and make a smooth, complete surface (Carrara, Bitelli, Carla 1997: 458). Using the completed contour map as the input, ArcMap generated a TIN storing the elevation data in a triangle-based vector surface. The generated TIN created a smooth elevation surface for old Port Royal, but because of the triangular constraints of the surface, the calculated TIN projected across Chocolata Hole, bringing the submerged area to an elevation around 4m above sea level. The TIN was clipped with the shoreline reconstruction to remove the excess data from the Hole, ridding the submerged area of elevation data and creating the completed smooth elevation surface for the pre-earthquake peninsula (Appendix II, Figure 9.10). The TIN was then converted into a DEM so that the stored elevation data could be projected in 3D (Appendix II, Figure 9.11).

Extracting Z Coordinate Data

Since the change in elevation is so low throughout the peninsula, projecting the elevation data in 3D came with a unique set of challenges. While the elevation data was

stored in the individual raster pixels within the DEM, the very slight change in elevation made it such that extracting the Z coordinate data in ArcGIS' 3D imaging software, ArcScene, caused an inherent distortion to the visual representation of the data. To this end, the 3D data was configured in both ArcScene, to maintain the data in a native GIS format, as well as in *Rhinoceros 5*, to help eliminate the visual distortion. In ArcScene, the data was first floated on a custom surface within the *Elevations from surface* value under the *Base Heights* layer property. As the DEM had the data stored in metric units, no conversion was applied, and no offset was necessary as the elevations began at sea level. This created a functional 3D model based off of the stored elevation data. The model, however, could not adjust to a point where all edges of the model were set to zero, so as to be equivalent to sea level. This poses only a slight problem, and only in the shoreline surrounding Chocolata Hole (Figure 4.7). To correct for this, the model was saved as a WRL file and opened in *Rhinoceros 5*.

Within *Rhino*, the scene could be opened, and a plane created at zero to represent sea level. The reconstructed shoreline and the plane were then joined and holes filled using the *Patch* function native to *Rhino* to create a solid model with the shoreline edges pulled down to fit to the zero plane (Figure 4.7). For the purposes of adding the buildings into the model, forcing the shoreline to the zero-meter plane is not necessary, as the elevations for the area at Queen Street and Lime Street are projected without distortion. However, creating a second model in *Rhino* not only allows for a watertight model of the data down to sea level, but also provides for the opportunity to work with

the data in a local coordinate system outside the constraints of the global coordinate system provided by a GIS.

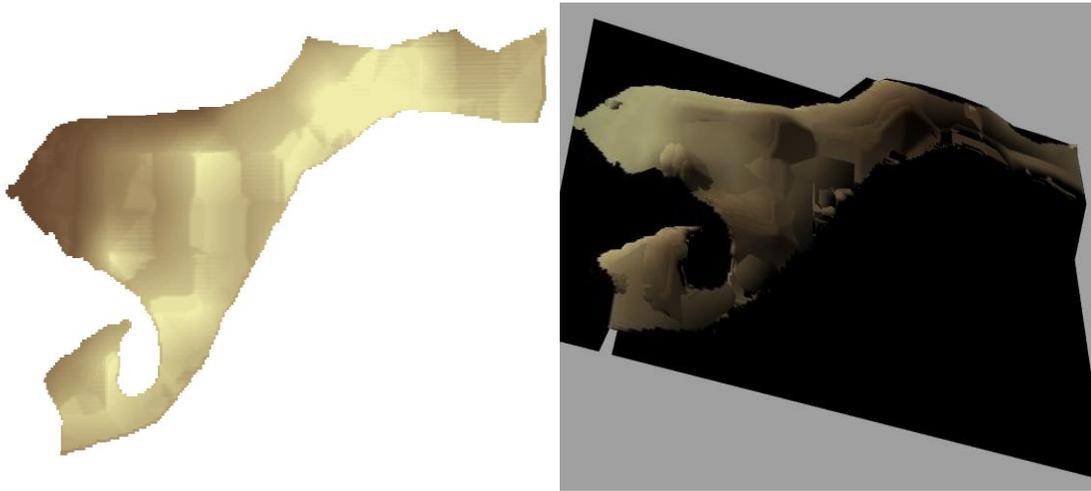


Figure 4.7: The old Port Royal shoreline as reconstructed in ArcScene (left) and *Rhino* (right)

Problematizing the Shoreline Reconstruction

More than the potential reconstructions of the buildings, reconstructing the contoured shoreline of Port Royal posed difficulty for two substantial reasons. The first has to do with a lack of data available for the current topography. By nature, Port Royal is a small, low elevation spit of land. Less than 0.2 square kilometers in area and with an elevation no higher than three meters (Pawson and Buisseret 1975: 174), Port Royal represents a flat and hyper-local land mass, which does not lend itself well to the traditional sources of ascertaining and interpreting topographical data.

A lack of rich geographical data collected by the State of Jamaica and governmental limitations on data collection from international agencies limit the scope of data available for the island as a whole, and where data is available, Port Royal's diminution leaves it with relatively little data in order to fit the larger data set's standard scale. Thus, ascertaining the elevation of the current land that overlaps with the 17th-century boundaries of the city was left to extracting data from an ASTER Global Digital Elevation Model (ASTER GDEM).

Aster Global models are generated with a resolution of 1 arc-second, giving it a 30 x 30m horizontal grid. This means that elevation data, when masked by the Port Royal shoreline, generates about forty unique pixels of data, each representing the maximum elevation of the 30 x 30 m grid square assigned by the ASTER GDEM. The hyper-local nature of Port Royal, however, means that much of the contour data is lost in the grid, as each pixel only represents a maximum elevation. Thus, elevations of the

current land mass excluded much of the data necessary to create a comprehensive reconstruction.

The second issue arose from the shift of the land that sunk into the water during the 1692 earthquake. The area excavated by Hamilton in the 1980s was selected because it was largely the product of liquefaction (Hamilton 2008: 265). As the buildings at the corner of Lime Street and Queen Street essentially fell and sunk straight down into the liquefied substrate beneath the buildings, there was relatively little slide or shift in the remains of the excavated buildings, themselves (Hamilton 2008: 265). However, the prospect of extruding the architectural remains upward from their contours below the seabed cannot be considered due to the later 1907 earthquake. While currents and atmospheric events over the centuries shifted the seabed, the subsea area was likely most altered by the tectonic shifts from the 1907 earthquake. Any model developed from this combination of global and historical data must either find a means of addressing these limitations, or otherwise acknowledge a greater margin of error in the reconstruction process.

CHAPTER 5

SIMULATING THE STRUCTURES OF BUILDINGS 1-5

Domestic and Merchant Architecture in the 17th-Century Port Royal

In many ways, architecture in the English colonial Caribbean did not differ much from the traditions in England. Domestic dwellings maintained largely the same elements though generally repeated on a grander scale due to the availability of land in the colonies versus the relative density of cities such as London (Gravette 2000: 41). One notable change was the movement of the hearths and often much of the kitchen fixtures to the exterior of the building, generally within an enclosed courtyard near the rear entry to the main house (Mintz 2009: 19). In the wickedly hot Caribbean climate, this served to eliminate trapping excess warmth inside the buildings due to cooking (Mintz 2009: 19). Additionally, shutters were an integral part of the colonial Caribbean home, often set on a tilting window box with louvered sides running up to the top of the window. These shutters were hinged either from the sides or the top so that they could be opened to allow for more light and the more ready flow of air (Gravette 2000: 66). Likewise, in some cases windows may have been constructed of a frame and lattices without glass panes, to keep air moving throughout the house. When necessary, the shutters were used to close the windows (Nelson 2016: 71).

Jamaica perhaps more than some other colonies held on strongly to English architectural modes and traditions at least up to Port Royal's destruction at the end of the 17th century. Strong separation between colonists and slaves led to a distinct rise of

wattle and daub for small and transient structures meant to house the slave population (Crain 1994: 60), while the Jacobean traditions of tall brick houses with gabled roofs dominated amongst the colonists (Crain 1994: 105). Nog architecture, a method of building using a wooden frame with masonry infill such as brick, stone, or concrete, was used for both small slave and large colonial structures around the island, providing a small point of overlap between the otherwise stratified material remains of these two distinct groups (Crain 1994: 62).

Port Royal did not follow the building tropes of much of the contemporary Caribbean, though, nor was later English settlement in Jamaica a strong indicator of the development or aesthetic of Port Royal. Restricted by the diminutive dimensions of the peninsula, the town was forced to grow upward and inward, creating an incredibly dense city where homes would often stand with side walls directly abutting and buildings rising regularly to three or four stories (Buisseret 1980: 18). As the city was originally intended to be a small port and military fortification, it was never planned as later cities such as Kingston and Spanish Town were, but rather allowed to grow somewhat haphazardly in any direction that could accommodate it (Buisseret 1980: 18). The large houses that would come to mark later colonial Jamaican towns were notably absent from most of Port Royal, excepting perhaps the estates of the Governor and colonial officials (Buisseret 1980: 18). Instead, townhomes lined the streets much as they did in London, and the expanses of property enjoyed by colonists in some neighboring islands and even the Jamaican interior were substituted for small, sometimes shared yards (Trussell 2004:

57). Kitchens remained outdoors, though, as even in the compressed space the additional heat generated by the hearths was too much to keep in the homes.

By the end of the 18th century, a distinct feature had become commonplace in colonial Jamaican architecture, that of buildings constructed with their upper floors projecting out over the sidewalks and footpaths, in the traditional European medieval manner, thus creating covered walkways to shelter pedestrians from the heat of the Caribbean sun (Maudlin, Herman 2016: 188). This particular architecture was the product of combined merchant and residential structures, wherein the ground floor functioned as a storefront or merchant space, with the upper floors serving as residential space for the shop owner and their family (Maudlin, Herman: 189). With the ground floor set back from the street and sheltered by the colonnade created by the buildings' upper floors, merchants were able to create a public space that was both elevated off the dirt of the street and sheltered from the sun and rain (Maudlin, Herman 189). While this likely was not a feature present on every structure prior to the 18th century, but some scholarship suggests that early colonial Jamaican structures experimented with overhanging second stories as a means of climate control for the lower level of the house (Maudlin, Herman 2016: 188). If such is the case, it is possible that the awnings and overhangs frequently depicted in reconstructions of Port Royal's 17th-century architecture were an early manifestation of early overhanging upper stories. In fact, in some of his reconstructive drawings of the city, historical architect Oliver Cox suggests that at least some of the Port Royal buildings had a slight projection at the second or third story to create covering for those below (Saint 2010: 34). Much the same could be

seen in London before the fire, where timbered overhangs were often attached onto brick structures to create a slight outward projection covering the area immediately below (Nelson 2016: 82).

Otherwise typical of 17th-century urban English architecture, Port Royal favored closely bunched homes arranged in a townhome-like fashion. Even if original intent did not dictate that structures should share walls, the necessary density of the urban environment was such that buildings were constructed using the existing walls of already-standing structures, or otherwise walls were raised in direct contact with other walls, functionally creating a single, thicker-than-average shared wall (Nelson 2016: 72).

Where Port Royal architecture necessarily had to align with Caribbean tradition over urban English tradition was in placement of the kitchen. As the climate dictated that the hearth must be outside, the fundamental layout of the Port Royal kitchen was largely divorced from its English counterparts. Whether the whole of the kitchen was outside or just a *cook room*, which contained the hearth and immediate preparatory areas is somewhat speculative, as John Taylor's travel log states "here they need not feare paieing hearth mony, for they build noe chimneys, but only in their cook rooms, which stand at some distance from their houses" (Taylor 1886: 252). Most houses in Port Royal had small individual yards, or otherwise operated with a shared yard between multiple tenants of one building (Trussell 2004: 57). In each yard, there was a brick hearth, generally at opposite ends of the yard from the home, so as to reduce the amount of heat that could come in through windows or doors. The cook room, itself, was set up around this hearth, most likely with a shade built over the area, and in some cases with an entire

shed constructed around an entire kitchen (Nelson 2016: 224). These shades and shed, if they followed the typical pattern in the British Caribbean at the time, would have been more closely related in architecture to the impermanent structures erected in conjunction with permanent urban settlement, such as utility sheds and slave quarters (Darrington 1994: 7). In fact, the kitchen often operated by slaves and servants in many colonial Jamaican households, the cook room may well have been seen largely as a servant or slave's dominion, and thus aligned more closely with the physical typology of the servant quarters, though likely aesthetically made to look consistent with the rest of the house by their brick construction. In addition to a cook-room, a cistern was generally located in the yard, supplied by rainwater and occasionally shared between structures (Darrington 1994: 96).

Little architectural evidence of 17th-century slave quarters survives throughout the Caribbean, and virtually no archaeological evidence of slave settlement has been noted in Port Royal. What evidence does exist of early urban Caribbean slavery suggests that enslaved people serving urban households in the Greater Antilles had less contact with white society than enslaved peoples in on the American mainlands. Analyses of Bridgetown in Barbados and Spanish Town in Jamaica indicate that enslaved peoples often lived in their own collective settlements on the outskirts of the urban areas, occupying barracks-like structures in camp-like areas that generally featured shared amenities such as single kitchens for several of these barracks structures (Nelson 2016: 224). Port Royal, with its limited land, likely could have only accommodated such outside of the city gates. Thus, slaves would have either been housed in impermanent

settlements outside the city walls, which were neither investigated for nor excavated, or more likely they were otherwise housed directly in or near the homes they served, which would have been unique but not unheard of for the time (Meyers 1999: 202; Heidtke 1992: 92-100). As both red clay pipes and Yabba ware, indicative of slave populations, have been recorded abundantly within the city walls, as well accounts of slave quarters in back of the home, it is most likely that slaves shared homes or had small settlements in common areas such as yards within the English settlements of Port Royal (Pawson and Buisseret 1974: 169).

Port Royal and Bridgetown: Comparative 17th Century English Colonial Sites

In establishing a spatial analysis of Port Royal, comparative examples were limited if only due to the high concentration of individuals within such a small space. Prior to the 18th century, the British New World had not seen a settlement like Port Royal in terms of density, making parallels between the Jamaican city and other New World settlements loose and somewhat arbitrary. Instead, although on a smaller scale, perhaps the best point of comparison for Port Royal was London, itself a dense and relatively unplanned city with access to large amounts of wealth and commercial enterprise. In particular, comparative iconography shows strong similarities between London before the great fire in 1666 and the city of Port Royal, which despite growing by its greatest

amounts after the fire, maintained early 17th-century London's unplanned streets and passageways, as well as its close-quartered homes and merchant spaces (Figure 5.1).

Port Royal's close parallels to London originate from its unique position within not only the Caribbean, but the colonial world. Toward the second half of the 17th century, when Port Royal experienced its greatest growth, most English colonial holdings in the New World functioned to facilitate agriculture and the acquisition of raw materials for production back in the English homeland. Jamaica, like many of the Caribbean islands, functioned primarily to provide sugar to Europe, and thus had an economy largely based on plantations where sugar cane was grown and refined for consumption across the



Figure 5.1: Detail of map of London from 1580. Reproduced from the National Maritime Museum, Greenwich, London (Londinium Feracissimi An Gliae Regni Metropolis).

Atlantic (Pawson and Buisseret 1974: 91). The wide swaths of land necessary to facilitate sugar cultivation were not conducive to the development of urban spaces, and thus most of Jamaica remained a rural and agrarian part of English colonial society well into the 18th century. The area that would become Port Royal could not fit into that plantation economy, though. It did not have the space nor the fertile land necessary to develop sugar cane as a crop. Rather, its defensive position guarding the mouth of Kingston Harbor made it a natural military location, as well as an ideal place to load and unload the large amounts of sugar being produced in the interior of the island (Pawson and Buisseret 1974: 103). With the merchant class came the need for storehouses, supply houses, inns, pubs, and other places of commerce and service, making Port Royal an urban center and commercial hub.

With the interior of the island focused on sugar production, slavery also became critical to the colonial workflow, and much as Port Royal served as a station to load and unload sugar cargo, so too did it function as a hub for the Caribbean slave trade (Zahedieh 1986: 575; Johnson 2000: 74). Slaves newly arrived in the New World would often be taken to Port Royal to be assessed and sold. This, combined with the city's high tolerance for gray and black-market merchants, led to a steady growth in merchant activity in the port, bringing in both increasingly larger populations and greater monetary wealth, allowing the city to grow into an urban environment that far exceeded the reaches of any agriculture-based colonial cities, including those in modern America, as well as any of the Caribbean island cities.

While Boston would eventually come to rival the population of Port Royal, the colonial capitals served two very different functions based on two very different economies. Port Royal filtered in most of the capital from the sugar plantations in Jamaica's interior, bringing the goods to trade and shipping them out across the colonies and across the seas (Pawson and Buisseret 1974: 103-104; Johnson 2000: 44). In that way, the closest parallel to the structure and daily function of Port Royal in the 17th-century English New World was Bridgetown, the capital of the sugar island colony of Barbados (Buisseret 2006: 72). Like Port Royal, any formal plan for Bridgetown was outpaced by the city's natural growth, and like Jamaica, Barbados funneled much of its income from the sugar plantations on the interior of the island through the colonial capital before exporting out to England and the North American colonies (Buisseret 2006: 72; Buisseret 1980: 18). Where Port Royal was limited by the size of the landmass on which it was constructed, though, Bridgetown had room to grow out instead of up, and so can function as a comparison in terms of structural aesthetics and features in the colonial Caribbean, but not in terms of overall form of the urban space.

Bridgetown, for its part, was settled earlier than Port Royal, with efforts to colonize Barbados beginning in 1628 (Buisseret 2006: 72). Like Port Royal, it shows no signs of having a formal city plan, but unlike Port Royal, it had organized spatial distribution centering on agriculture, with settlement developed based upon the needs of merchants to build warehouses for sugar stores that would make their way to the rest of the English world (Buisseret 2006: 72). Early buildings in Bridgetown were thatched, though they would later be replaced by brick and tile structures due to devastating fires

(Nelson 2016: 72). Far to the south and east of the Caribbean settlements, Bridgetown was fortified, but largely out of the way of other colonizers, and thus was not only less fortified than more central cities such as Port Royal, but considered a safe enough area that ships were regularly taken ashore, repaired, and re-caulked. This made Bridgetown a relatively safe port, which helped it prosper as a center of trade, especially amongst the Leeward Islands (Garcia 2017: 169, Crain 1994: 21). In this way, the growth of Bridgetown reflects that of Port Royal, though over a much more extended period of time. Thus, as a populous, urban English Caribbean port, Bridgetown can provide some insight into settlement patterns in other major English cities within the Caribbean. Structure styles and decorative choices may be indicative of widespread trends in colonial Caribbean architecture, though it is known that certain features common in the rest of the Caribbean, such as solid shutters, were not commonly found on Barbados while other features, including gables decorated with intricate fretwork were unique to the island (Crain 1994: 64). As much of the historic city stands today, Bridgetown as a comparative settlement also offers more readily documented evidence than other historic Caribbean ports, many of which have been partially or fully rebuilt in response to population increases, destruction by natural disaster, an increased demand for tourist accommodations, or some combination therein. Where Bridgetown cannot provide insight into the structure of Port Royal is in the dense urban development. As the Barbados port was not isolated in the same way as the early Jamaican capital, it was allowed to spread both up and out, and thus never had to deal with the dense spatial strains put upon Port Royal.

To contextualize the density of the city, only archival data of mid-17th-century London may provide reasonable parallels. Urban surveys completed by Ralph Treswell in the early 16th century provide some of the best data for the dense, narrow, haphazard urban patterns prominent in London before the fire. A particular drawing made by Treswell of what was then referred to as *West-Cheap* in what is now the financial center of London shows densely-packed, three-story townhome style buildings centered around a church, each with gables running the length of individual units, and each with broad windows for every story of the building as well as a window for light set into the gable (Figure 5.2). This style factored in heavily with the reconstructions of the five Port

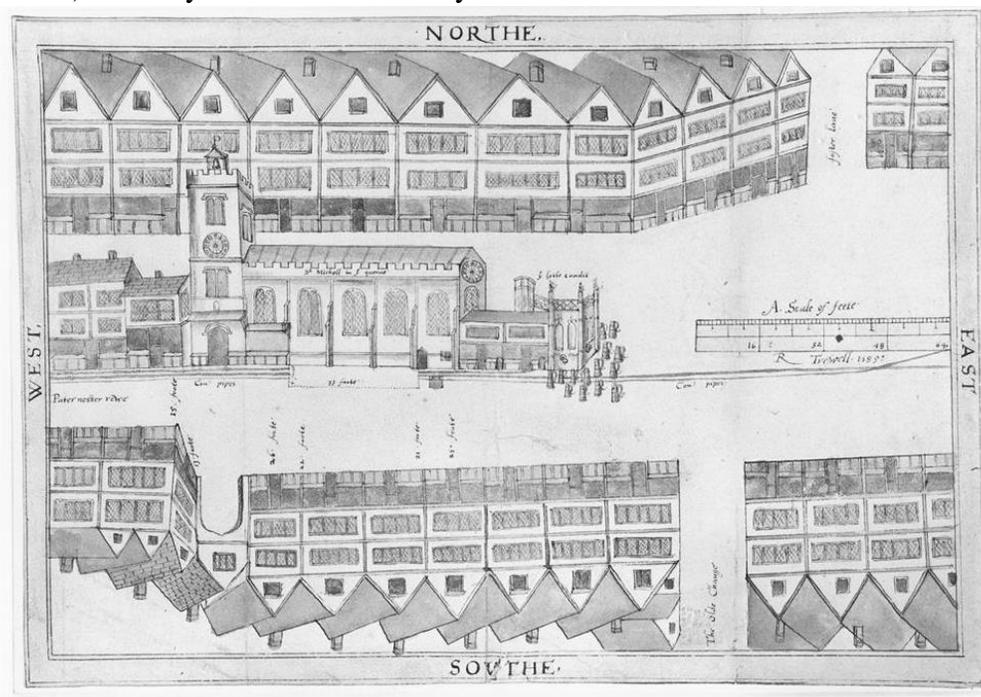


Figure 5.2: Treswell, R., 1585, West-cheap (i.e., Cheapside), London. Reproduced from ARTstor Digital Library.

Royal buildings analyzed in this thesis, as their physical remains suggest similar building heights, roof structures, and other shared architectural elements.

Building 1

Building 1 was a brick building spanning 16.15 m wide at the front facing Lime Street, and stretching 14.33 m deep. Hamilton and crew began excavations on the structure in 1981. The structure spanned six rooms on the ground floor, three in the front and three in the back, with a volume of brick from the excavation that suggests the building had at least two stories (Hamilton 2017, Trussell 2004: 46-48). Rooms 1, 3, and 5, all located in the front of the building, were connected by a wooden doorway to rooms 2, 4, and 6, respectively, forming three parallel units, each with their own yard and hearth. As no interior means of passage exists between the six units, it is likely that each unit housed a separate business or a distinct commercial activity. The building, itself, likely underwent an expansion and renovation, as the patterning of the brick uncovered during excavation suggests that the back three rooms were added on after the front portion of the structure was already complete (Hamilton 2017, Trussell 2004: 46-48). The density of brick is consistent across the front and back areas of the structure, suggesting that both the original building and the later addition had two stories.

The first unit, comprised of rooms 1 and 2, was suggested in preliminary analysis to be a cobbler or wood turner's shop, as large quantities of leather scraps and shoe soles, as well as a wooden lathe and planks were found in context with this portion of the building (Hamilton 2017, Trussell 2004: 48). A great number of cut animal bones and

sea turtle shells were further recorded in room 2, suggesting butchering and food preparation, though it is unknown as to whether this was for a commercial purpose. The second unit, comprised of rooms 3 and 4, may have served as a tavern based upon the over 60 dark glass liquor bottles found there. In addition to the bottles, jugs, tankards, and kegs were found between the two rooms (Hamilton 2017, Trussell 2004: 48). The third unit, comprised of rooms 5 and 6, housed a large collection of unused kaolin clay tobacco pipes, as well as glass bottles and some pewter plates (Hamilton 2017, Trussell 2004: 48). This led to preliminary analysis suggesting the unit was a pipe shop, a wine shop, or some combination thereof.

The above spaces in the structure's second story would likely have served a domestic purpose, turning each unit into a live-work space, as was common in other major British cities including colonial ports such as Bridgetown and other dense cities like London. As no articulated portion of the second stories survive, though, their ultimate functions and layouts are speculative.

The reconstruction of the building looked to the three-unit layout to give it form. Specifically, the model was set up at its base using the dimensions of the recorded building footprint to be 16.15 x 14.33 m. This footprint was then extruded upward to represent two stories with the base height for each story set at 2.74 m. Such a height would have been somewhat liberal for non-aristocratic urban homes in England at the time, but the Caribbean heat would have caused some necessity for higher ceilings, allowing the warmest air to rise while cooler air blown in by the sea breeze entered low through the windows. Such a ceiling height, then, would not be unreasonable for the

location. With a base height for both stories set, three parallel pitches were added to give the roof its shape, one running the length of each unit. This specific form was not as common as a single pitch in 17th-century English architecture, but depictions of both London before the fire and houses in Bridgetown show spaces with this style (Nelson 2016: 1992; Schofield 1987: 23). It is particularly appropriate for building 1 as the great width of the original structure would have created an architectural challenge to find a ridge beam long enough to fit the building, light enough to keep from dragging the roof down, and sturdy enough to survive the extreme storms of the Caribbean. Running individual pitches along the length of each unit, though, drastically shortened the necessary length of beam for any one pitch, making the building more secure and easier to construct. When the second units were added in the back, they likely would have each had their own, new ridge beam installed and the seams in the roof covered up by roofing material such as shingles or thatch. A small joint may have connected the pitches to offer lateral stability, but it is unlikely that entirely new beams would have been put in to accommodate the extended pitch.

The model of building 1 was finished with one front door, one first floor window, and two second floor windows for each unit. The doors were traced in size and position from the dimensions provided by the site map, while windows were drawn in based on common architectural practices from the period. Each unit was shown with a wood-framed, multiple leaded sash window on the first story, centered vertically at 1.52 m, putting the window's vertical center at the same place as the story's vertical center. Windows on the second story were likewise made so that their vertical center was equal

to the center height of the story at the base of the gables. Windows on the second floor were made in the Caribbean window box style, with two sets of six panes held in with lead lattices and separated by a simple mullion (Gravette 2000: 67-70; Nelson 2016: 71). The uppermost windows within each gable were made with a more traditional casement style, as they likely were not practical to open, or functional for anything other than light. Subsequently, they make use of the traditional four pane window style of the time, with each pane held in by leaded lattices, as would have been common practice in 17th century English colonial architecture (Pickles, McCaig, and Wood 2017: 13). These features, together, provide a basic reconstruction of the exterior of building 1, and include enough points of sight and entry to allow for spatial analysis of the structure simulation in relation to its surrounding environment.



Figure 5.3: The reconstructed front of Building 1

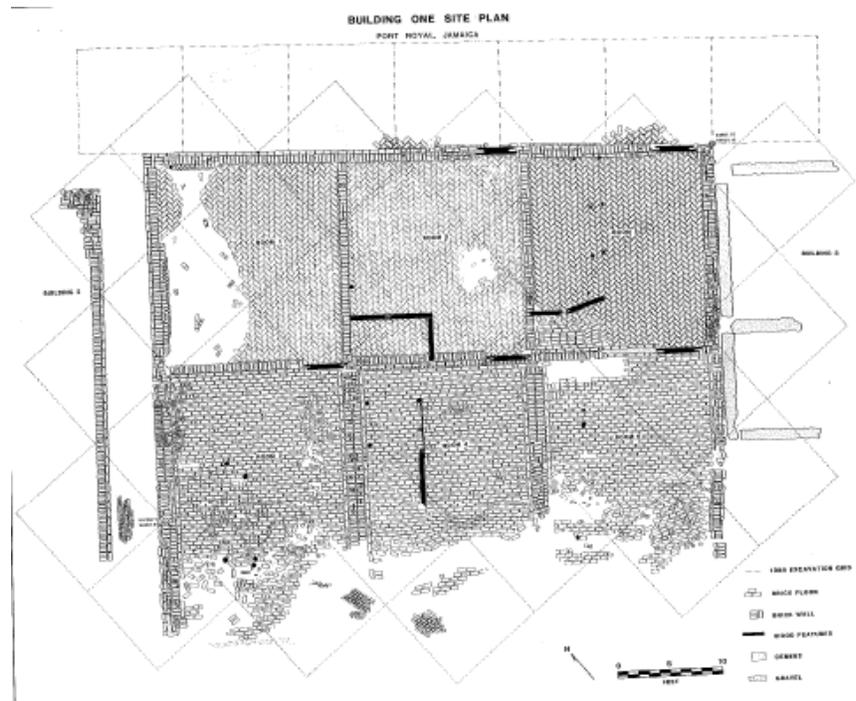


Figure 5.4: Site plan for Building 1 as recorded by Hamilton and team (Hamilton 2017)

Building 2

Building 2 faced outward toward Lime Street but other than this, excavators were able to assess relatively little about the function or purpose due to the advanced level of deconstruction caused by the earthquake. The density of the bricks around the exterior walls suggests that this, like many of the buildings on this block, was a two-story structure (Hamilton 1988: 9; Trussell 2004: 50). Only fragments of two exterior walls remained, along with a plaster floor in one room and a brick floor in a second room (Hamilton 1988: 9; Trussell 2004: 50). Subsequently, neither the size nor the function of the building could be estimated with any accuracy.

Due to the lack of information regarding building 2, the reconstruction was intentionally made simple. The high density of both people and structures in Port Royal suggests that the width of the building would have more or less occupied the distance between building 1 and the corner of the street, where it likely abutted the yard of another building. Two front doorways suggest that the building had two sections to it, possibly made to be separate units as in building 1. Thus, the reconstruction was given two doors, and a forward-facing window for each unit on both the first and second floors. The depth of the building was replicated based on the maximum extent of the existing exterior wall. The height of each story was estimated at 2.74 m to stay consistent with the spacing in the other buildings, and the roof was reconstructed as a simple hipped roof (Nelson 2016: 95). No additional detail was added so as not to create an overly-elaborate simulation of a structure about which little is known.

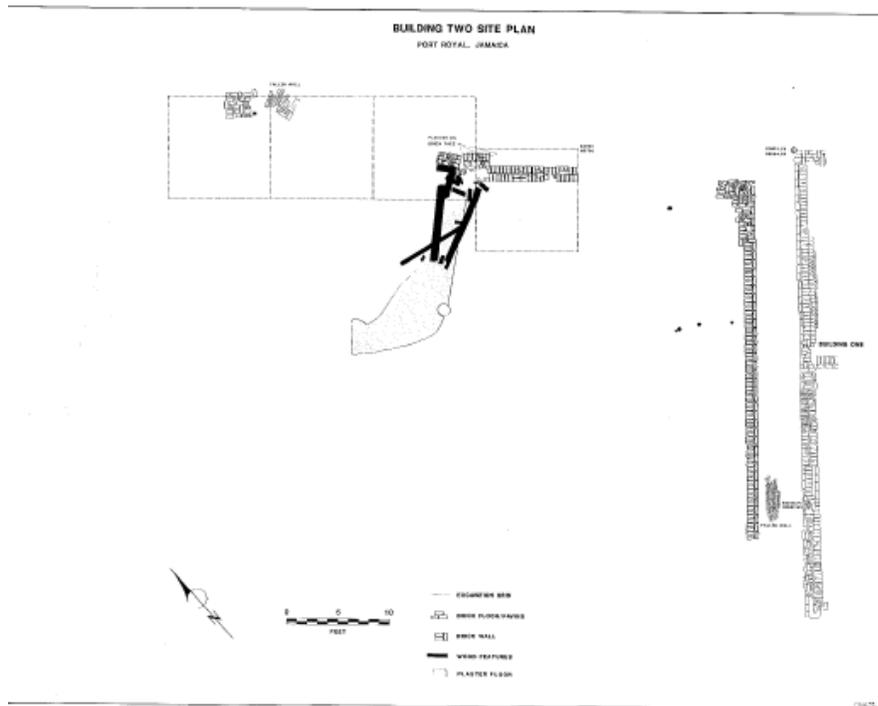


Figure 5.5: Site plan for Building 2 as recorded by Hamilton and team (Hamilton 2017)



Figure 5.6: The reconstructed front of Building 2

Building 3

Like buildings 1 and 2, building 3 faced outward toward Lime Street. Architectural preservation was somewhere between that of building 1 and building 2, but enough remained to provide probable estimates for the structure. Building 3 was a timber-frame building of about 11.58 m width and 8.23 m depth. The structure was post-fast, and had raised sills where necessary on top of a mortar foundation, and likely had a staircase between the two floors in the rear of the interior (Hamilton 2017, Trussell 2004: 51). The building was comprised of four rooms, and unlike buildings one and two, there was no discernable separation of units within the structure. Rather, it is possible that continuous traffic could have been facilitated between all rooms of the structure. It has been suggested by excavators that the back two rooms were possible extensions of the yard due to the remains of a cook room in the area (Hamilton 2017, Trussell 2004: 51). If that is the case, the depth of the covered building would be somewhat shorter, and the remaining depth comprised of walled-off but uncovered rooms as a part of the yard complex, making the building, itself, around 5.49 meters deep. The function of building 3 was not as immediately clear as that of building 1. Remains of unused kaolin clay pipes, corked and monogrammed wine bottles, and sets of scales and accompanying weights have given rise to the theory that building 3 served as a storage area for the activities in building 1, or otherwise as a storeroom for a known outdoor market nearby (Hamilton 2017, Trussell 2004: 51).

The reconstruction of building 3 was kept smaller to fit the overall stature of the structure. The building was made as a two-story structure in accordance with the size of

the post holes, but each story was estimated at around 2.5 m unroofed, bringing the overall height down somewhat from the adjacent buildings, though the roof does add some additional height on the second story. This shortened stature assumes that the building did, indeed, serve in a storage capacity, as if the first floor did not regularly see workers and customers for extended periods during the day, it may not have needed the same vertical clearance to allow warmer air to rise while the sea breeze blew in. The additional height provided by the hipped roof on the second story would have compensated for this shortened overall stature, giving any living spaces above the storage area better ventilation. Each room on both the first and the second floor was provided with a large window facing Lime Street, and each window was vertically centered at the same height as the vertical center of the building story, just as in buildings 1 and 2. A hipped roof was used to top the building as a number of 18th century structures from around Jamaica show a similar style (Crain 1994: 75-77).

Rooms 2 and 3 were then replicated as walled-off, open-air extensions of the yard. A wall was continued backward to the maximum extent of the walls recorded during excavation, and a back wall was created following the maximum width of the reconstructed building, giving the walled off area a depth of 2.74 m from the building to the end of the wall, and the same 11.58 m width as the building. The walls were brought up only to the height of the first story at 2.5 m, as it was unlikely the wall would have extended the full height of the building. Though divisions in the wall area were recorded during excavation, no divisions were included in the reconstructed model as they would

not serve any function in later analysis. It is worth noting, though, that this is the area in which the building's likely cook room was discovered.



Figure 5.7: The reconstructed front of Building 3

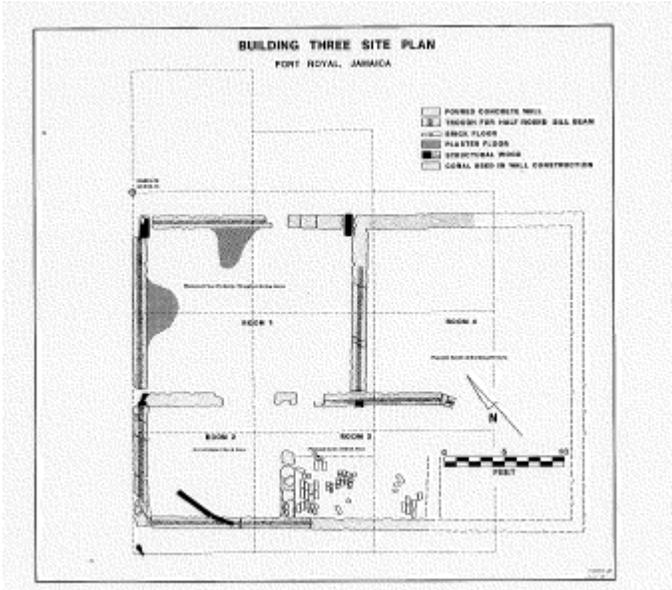


Figure 5.8: Site plan for Building 3 as recorded by Hamilton and team (Hamilton 2017)

Building 4/5

What came to be labeled as Building 4/5 actually represents a two or three structure complex with Building 4 and two rooms of Building 5 facing an extension of Lime Street. According to the archaeological record, this forward portion of Building 5 was the first portion of this complex to be constructed. Wall thickness indicates this forward portion would have stood two stories high. The two rooms of the primary structure each had their own entrance, and a large collection of pewter plates has led researchers to interpret Room 1, where paying patrons were served. Room 2, for its part, allowed access to the stairway leading up the building's second story, and also contained a large number of uncorked glass bottles and unused kaolin clay pipes at the time of excavation, leading to the conclusion that it may have been a storage area (Fox 1998: 34). A two-room extension of Building 5 was later constructed on the east side of the building, perpendicular to the rear wall of the main structure. This extension had thinner walls, indicating a one-story building (Hamilton 2017, Trussell 2004: 54). Building 4 likewise had walls indicating a single story, and likely faced out onto the Lime Street extension (Hamilton 2017, Trussell 2004: 54).

Building 4 was comprised of two rooms, each leading to their own yard with an exterior cook-room at the back of the yards, with the building itself spanning 10.75 by 5.2 m. Much of the function and structural interpretation of Building 4 was complicated by shift from the earthquake combined with the remains of an approximately 21.3 m ship, which was forced into the building during tidal activity after the seismic shock. Subsequently, the reconstruction of the building was left simple, with two doors at

opposite ends of the building and broad, low windows closer to the common wall between the rooms. The windows were reconstructed to stay consistent with the casement style present in the other buildings, and the maximum extent of the structure before the start of the roof was set at 2.74 m. The roof, for its part, was extended up one meter and given a hip to distinguish it from Building 5. The yards for the building were not reconstructed, though they were present and contained conspicuous cook rooms. However, not enough remained to distinguish structures and separations within the yards, and thus a reasonable representation could not be recreated.

The main structure of Building 5, comprised of Rooms 1 and 2, was reconstructed as a two-story structure, with each story also reaching 2.74 m before the edge of the roof, and the floors spanning 10.91 by 5.97 m. Doors were placed in accordance with the doorways identified during excavation, and one window was assigned to each room on the lower story, with Room 1 receiving a larger window as it was a larger room. As Room 2 contained the remnants of a stairway, it was speculated that the upper story provided living quarters, and thus the division of space for the upstairs was not assumed to mirror the downstairs. Instead, windows were evenly spaced across the upper story, and a simple hip roof capped the building.

The extension for Building 5 was taken up to the level of the first story and extended to the dimensions indicated during excavation, reaching around 5.97 by 4.27 m. It kept to a height of 2.74 m before the roof was extended. The roof was kept to a basic gable, and not tucked in at a hip to keep it flush with the main structure. No windows or road-facing doors were added, as no exterior doorway was identified during

excavation, and any windows would have been on the interior looking into the yard, thus not pertinent to the GIS model. A door was added at the back of Room 4, though, to provide passageway between the room and the hearth. Room 4 of the extension may have had a low wall but remained uncovered, as it is very near a hearth found in the Building 5 yard, and contained several wheat measuring weights (Smith 1995: 99). However, as there was often an indoor prep room along with the outdoor hearth and cook room, and clear connection existed between Room 3, which was also used for food preparation, and Room 4, the entire extension was roofed, with the assumption that the hearth area just outside the extension would not be. A yard and a cistern were found during the excavation, but likewise not included as they do not pertain directly to the GIS analytics of the project. The cistern is noteworthy, though, as it was shared by two additional yards that sat behind the cook rooms and yards of Buildings 4 and 5. This reflects the shared cisterns seen elsewhere in Port Royal, and speaks to the necessary resource sharing in the crowded space of the Port Royal city center.



Figure 5.9: The reconstructed front of Building 4/5

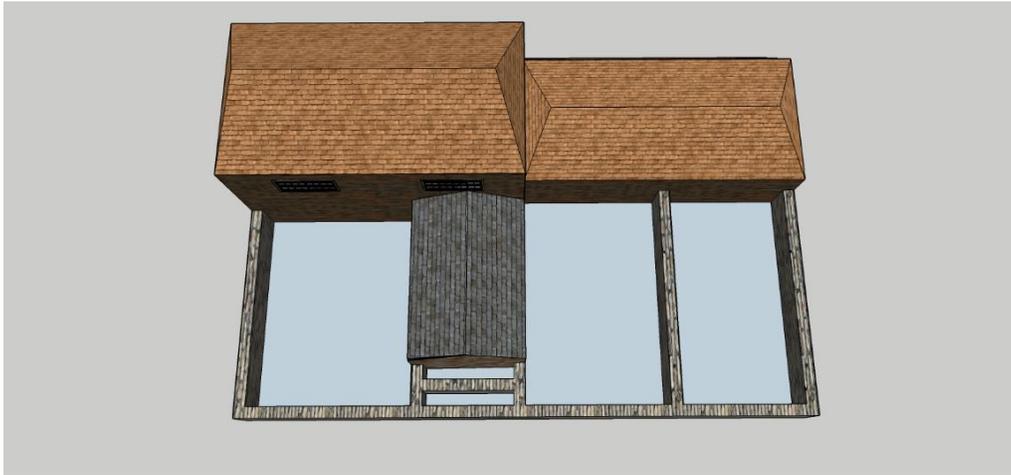


Figure 5.10: The reconstructed top of Building 4/5

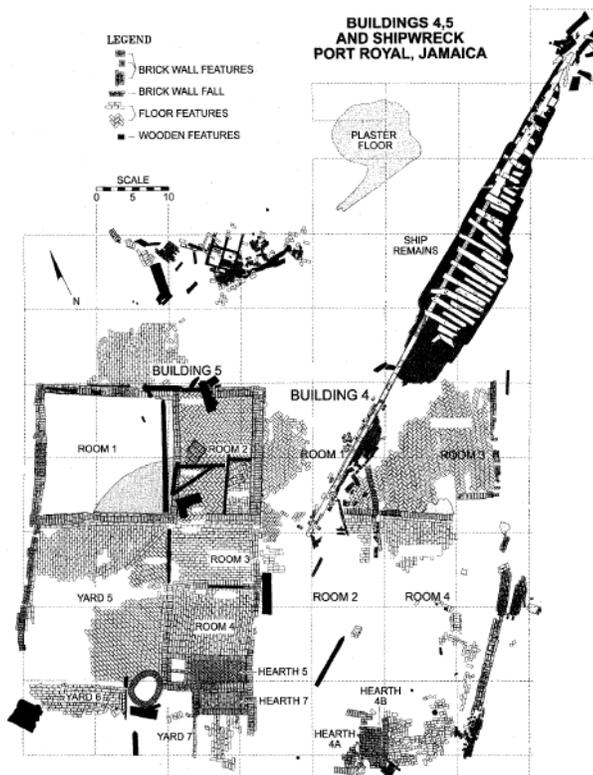


Figure 5.11: Site plan for Building 4/5 as recorded by Hamilton and team (Hamilton 2017)

CHAPTER 6

INTEGRATING 3D MODELS INTO A GIS

3D Modeling for GIS

While 3D recreations and GIS can work together, in some ways they serve as cross-purposes, complicating the matter of bringing models into a GIS. In many archaeological inquiries, GIS serves to log, track, and help pattern data (Conolly and Lake 2006: 2). Often, the primary focus of an archaeological GIS is the extant site, as the tools available in most GIS software packages deal with known rather than potential data (Conolly and Lake 2006: 5-6). 3D reconstruction, conversely, are based upon known data, but ultimately represent only one of many potential forms a site feature may have assumed. In this, alone, 3D modeling changes the nature of GIS, as while the software operation looks at any analytical process incorporating a reconstruction as fact, the resulting analysis is as hypothetical as the reconstruction, itself.

On a practical level, GIS and 3D modeling always had intersecting areas of functionality, but largely developed separately from one another, with GIS programs releasing their own 3D-enabled visualization platforms and modeling tools including *AutoCAD* and *Autodesk Maya* integrating the ability to add global coordinates to a model within the modeling software. Subsequently, interoperability between modeling programs and GIS programs has only recently become a point of discussion. Selecting a modeling platform that can readily integrate within GIS, then, becomes critical, as while most software can export a number of different 3D file types, the data generated by the

modeling platform can greatly impact the way in which a model is interpreted by a GIS software (Kemp 2008: 476).

Factors particularly worth noting are whether a model is scale-constrained, and if the exported model store 3D data. In particular, would exported models be able to maintain z-coordinate data in the scale in which they were created once imported into a GIS. If a model is created proportional to itself but unconstrained by a real-world scale such as meters or feet, it is not guaranteed to export in the correct proportions to match footprint dimensions within the GIS. Likewise, GIS platforms that are able to import 3D models can only accept certain file types. In the case of ArcGIS 10, supported file extensions are limited to .3ds, .wrl, .skp, .ftl, and .dae (Kemp 2008: 476). While a number of 3D modeling platforms can export models as a variety of different file types, generally models generated with certain software are better accepted by a GIS than others. In particular, models created in *AutoCAD* and *Google SketchUp* tend to be easily imported into a GIS, while models generated in a NURBS-based modeling program will have a more difficult time integrating into the scene (Abdul-Rahman, Zlatanova, and Coors 2006: 10). Moreover, most file formats make use of local coordinates rather than a global coordinate system. Thus, importing these files requires building them into the organizational space of the GIS in ArcCatalog and importing them as a new feature by editing the GIS layer, rather than importing them in one step through the use of a tool (Kemp 2008: 476).

Creating 3D models for GIS, then, must be intentional, as not all models and not all modeling platforms can be brought over at a later time should another decide that

they want to use it for GIS purposes. Models must be created with scale and ease of import valued at the beginning of the modeling process for proper integration into a GIS. If 3D data is to be shared with the intent that it could one day be included in a GIS, it must be made compatible from the beginning, as currently most GIS platforms do not place primary emphasis on interoperability with 3D designs, and cannot adjust for incompatible or partially compatible models.

3D GIS Applications in Archaeology

Despite the difficulties posed by generating 3D models for GIS, archaeological researchers have started making use of integrated 3D models in GIS to generate data-rich visualizations of sites. In particular, 3D GIS has found a home in viewshed analysis and site reconstruction within archaeology. While viewshed can, in practice, be done with stored z-coordinate data and requires no model, adding 3D visualizations help create a more complete, easily understood analysis. Likewise, while no GIS analysis performed on a site reconstruction requires an extruded model, integrating models helps provide a better visual for the stored z-data, making the GIS more intuitive to interpret for both researchers and external interested parties.

Viewshed analyses are common function of most GIS softwares, and allow researchers to determine a point's viewshed, or the area visible from a specific location (Conolly and Lake 2006: 228) projected over a raster image. Viewsheds depend largely on z-data of both the point of interest as well as the site, as a whole. Points can be adjusted to sit at certain heights above ground elevation, and parameters such as

directional blocks and visible distance can be set to help create a more realistic analysis based on the parameters of a site (Conolly and Lake 2006: 231). Viewshed analyses are a particularly useful tool in archaeology in that they do not require an extensive GIS background to perform them successfully, and they can offer up a wealth of information about what an individual or group may have seen from a given point in a site. This allows researchers to consider the significance of site layouts from the perspective of the individuals that occupied it, thus interpreting value based upon these perceived spatial relationships (von Schwerin, Richards-Rissetto, *et al.* 2013: 743). Such a tool has become popular in particular for ritual sites and monumental architecture, including churches, temples, and monumental tombs, as it allows researchers to see what would have been intentionally aligned with and made visible to these sites.

Reconstructions, for their part, do not require 3D models in that any analysis performed on a model can be performed on z-coordinate data linked to a 2D featured. In fact, in ArcMap, imported 3D models show up as two-dimensional polygons and polylines with stored z-coordinate data, and can only be viewed as 3D visuals when opened with ArcScene (Conolly and Lake 2006: 38-39). However, the integration of 3D models into a GIS 3D visualization platform such as ArcScene allows researchers to not only run 3D analysis tools, but to create a corresponding visual that makes the analytical results easier to interpret. This is particularly noteworthy in reconstruction analysis, as incorporating the 3D model allows anyone interacting with the data a visual aid to understand what the reconstructed feature may have looked like, rather than reducing it to a series of tables with dimensional data stored therein (Conolly and Lake 2006: 39). It

is worth noting that any tools run on a simulation represent a possible interpretation, rather than a factual analysis, as a reconstruction represents one of a number of forms a feature may have taken. Even well-documented, largely intact features are open to some interpretation, and thus any analysis that depends on data generated in whole or in part by interpretation must be considered with the same degree of skepticism as the reconstructed model, itself. However, that complication should be addressed regardless of whether the analysis is performed on 3D models or 2D footprints with stored z-coordinate data. To that end, incorporating models of reconstructed features within a site may still provide an easy-to-understand, interactive visual for GIS analysis and results. Such has already been seen in works under the MayaArch project, where an international team funded by the German Federal Ministry of Education and Research developed a series of 3D architectural models and associated data that can be queried and explored both as archaeological data and as a digital representation of the Mayan city of Copan (von Schwerin, Richards-Rissetto, *et. al.* 2013). Further efforts to incorporate field-recorded data into GIS models may further be seen in the work undertaken by archaeologists from the Swedish Institute in Rome. Using laser scanning and image-based 3D modeling, the team managed to integrate field-recorded, digital representations of the ruins of a Pompeian city block into a GIS (Dell'Unto et al. 2016). Such projects stand out as examples of not only the plausibility but the potential applications of integrated 3D archaeological data within a GIS, proving that while analysis may still be in development for such projects, it is still possible.

Integrating 3D Building Models within the Port Royal GIS

Bringing the models of the Hamilton excavated buildings into the Port Royal GIS posed a significant set of challenges. The building models were created in SketchUp, and the products were exported as .dae files. This file format was favored as though .wrl files can be saved with locational data, making them easier to place in the data frame in a GIS, they can be more difficult to adjust in that data frame, as not only the model but the locational data require editing. For small adjustments, such as aligning building corners to building footprints, such an editing process seemed impractical.

After the models were exported in an appropriate file type, a new multipatch feature, which stores data relevant to the outline of a 3D object, was created in ArcCatalog to facilitate importing the models so they could interact properly within the data frame. As the models were not georeferenced, they had to be brought in as a multipatch feature, which is positionable and referenceable. As each building

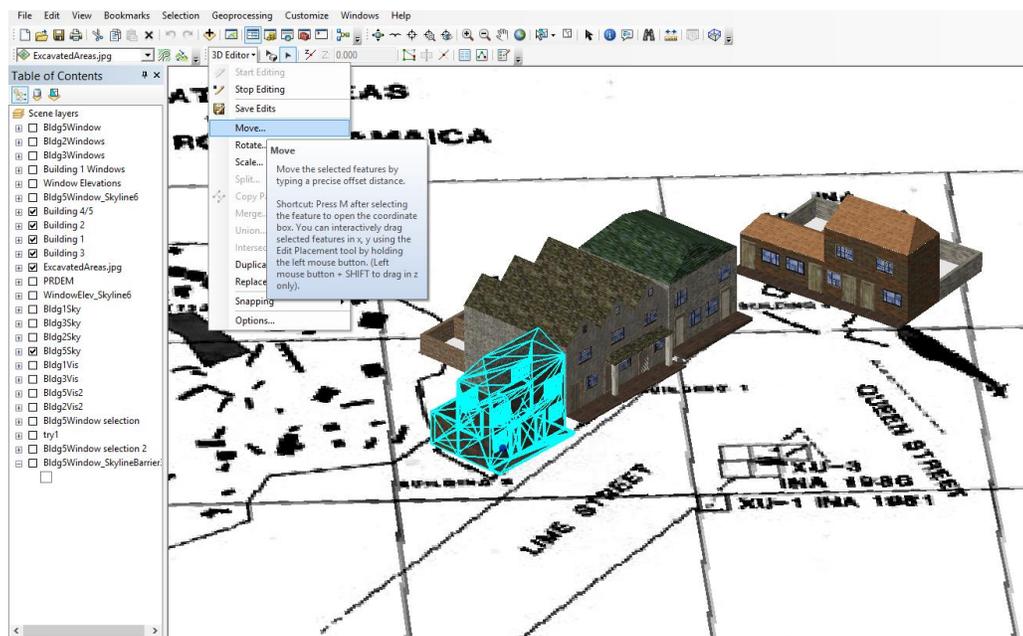


Figure 6.1: Adjusting model position in ArcScene

represented a discrete model, each had to be imported as its own multipatch feature. Each feature set was thus created in ArcCatalog under the larger Port Royal geodatabase to house all the building models, and each model had its own feature class developed as a multipatch feature, leading to four distinct multipatch feature classes. Each feature class was set up to align with the data frame, using the WGS_1984 global coordinate system. Once the features were created in ArcCatalog, they could be drawn directly into ArcScene, using the georeferenced excavation maps as footprints for the building models.

To bring the models into ArcScene, each multipatch feature class was added to the scene as a layer prior to editing. Once the multipatch was added to the data frame, an editing session was started so that a new multipatch feature could be created. With editing enabled, a single building multipatch was selected and the 3D visual brought in by importing the model data through the “Create Feature” editor tool. The model data was then brought in as a multipatch feature, and from there could be replaced with the fully integrated model by using the “Replace with Model” tool in the “3D Editor” menu (Tang, Lou, *et al.* 2016: 573). This brought the modeling data into the scene, and from there the model could be placed and rotated within the scene using the “Move” and “Rotate” tools, also located in the “3D Editor” menu (Figure 6.1). This process was repeated for each building model until all were brought into the scene, and properly aligned with their footprints. Once this was completed, all edits were saved and the editing session terminated (Figure 6.2).



Figure 6.2: The reconstructed structures overlaid on the 1981-1990 excavation map

When all building models had been imported into the Port Royal scene, they were set to sit on top of the land rather than at a zero elevation. This was accomplished by selecting “float on a custom surface” under the “Base Height” tab in the Properties window for each model. The reconstructed landmass was selected as the input for the custom surface, and the new properties were applied to each model. This brought the building models up to the elevations of the reconstructed landmass, and completed the process of integrating the building models into the GIS (Figure 6.3).



Figure 6.3: The reconstructed shoreline with integrated building models

CHAPTER 7

VISIBILITY ANALYSIS OF A RECONSTRUCTED PORT ROYAL

Visibility Analysis in Archaeological Reconstruction

Archaeology has traditionally held visibility as both speculative and of secondary concern, as analog interpretations of visible range from a particular site were at best estimations based on predicted data of what the landscape may have looked like. Historical archaeology has typically performed somewhat better in this sense, as historical documentation, cartography, and iconography have helped to contextualize visibility within a site without the need for dense mathematical reconstruction.

The notion that visibility should be outside of the primary concern of archaeological analysis, though, disregards the visible scape in which past peoples functioned and interacted. Visibility was a primary source of navigation, reference, and planning within settlement spaces, and a more complete understanding of a past site necessarily should include consideration not only of the site layout, but the ways in which peoples interpreted and interacted with the site, with visibility as a primary tool therein (von Schwerin, Richards-Rissetto, *et al.* 2013: 742). GIS has done much to change the way in which visibility can be analyzed within a site.

In the case of archaeological reconstruction, viewshed analysis has become one of the most popular tools, as it allows researchers to approach theoretical reconstructions with consideration to the physical, rather than perceived, landscape (Llobera 2003: 31, Nutsford, Reitsma, *et al.* 2015: 2). Viewshed takes into account the terrain within a

defined space, and in the simplest terms produces a binary analysis of a raster elevation dataset where cells that are visible are assigned a “1” value, while those that are not visible are assigned a “0” value (Nutsford, Reitsma, *et al.* 2015: 1). These binary values are displayed across the area of inquiry in contrasting colors to depict the terrain that would be visible from a given point within a GIS (Nutsford, Reitsma, *et al.* 2015: 1). Viewshed analyses pose a problem in that it more readily accounts for terrain than to constructed or artificial visual presences, and more significantly, it cannot determine visual significance without heavily modified parameters. A binary viewshed, alone, is unable to factor in conditions such as reduced atmospheric visibility and object-background clarity, and thus can only provide a single, rather than graded, value for visibility (Nutsford, Reitsma, *et al.* 2015: 2). This can be modified somewhat with the use of a fuzzy viewshed model, which employs an exponential distance decay function to factor visual significance into the analysis. In such an analysis, the significance of an object decreases the further it is from an observer point, assigning priority to nearby and thus presumably highly visible objects within the field of view (Llobera 2003: 34, Conolly and Lake 2006: 230). Viewsheds are further challenged by the visual significance of vertical features, as they can factor in only the height data stored within the GIS (Llobrea 2003: 37-38, Nutsford, Reitsma, *et al.* 2015: 2). This means that two different elevation models that share the same elevation distribution could output the same viewshed, even if the absolute heights on one model were double that of the other (Nutsford, Reitsma, *et al.* 2015: 2).

A number of methodologies have been proposed to address the limitations of viewshed analysis (Nutsford, Reitsma, *et al.*, 2015; Domingo-Santos *et al.*, 2011; Wheatley and Gillings, 2000), but in the case of much of the archaeological analysis for which viewsheds are used, adjusting for visual significance requires data that may no longer exist. Binary viewsheds, then, aid researchers in determining the distribution of a site across its given terrain and in doing so provide an initial set of data that can aid in determining visibility according to the rise and fall of the terrain upon which the settlement was built (von Schwerin, Richards-Rissetto, *et al.* 2013: 743). In reconstruction, however, modified viewshed analyses proves more useful in that it enables researchers to factor in the vertical significance of the reconstructed features, and thus derive a simulation of potential visible range from given points within a site. This is an especially useful tool for assessing the visual potential of large-scale architecture, including religious structures and monuments, navigational aids such as lighthouses, and urban meeting areas such as community squares and mercantile districts.

In addition to viewshed analysis, ArcGIS provides a number of tools that are able to break down visibility across terrain and between points. Of particular interest to the field of archaeology, the “skyline” tool allows researchers to project out from a given point and create a polyline feature that marks the point of separation between the features of the GIS and the sky (Guney, Girinkaya, *et al.* 2012: 160). In an archaeological context, this allows a researcher to project out from a given point to see what would have been the maximum extent of visible range factoring in topography of a

site. The tool allows users to set the surface radius as necessary, as well as the features within the GIS to be considered while creating the line of view that defines the skyline from a set point (Guney, Girinkaya, *et al.* 2012: 169). In reconstruction, this tool could be used to allow researchers to check a proposed simulation against historical documentation and iconography, in order to determine whether the proposed reconstruction clashes with historical accounts.

In a simplified function, skyline may be used as an aid to viewshed when extending out upon a flat surface to represent the maximum visible distance from a given observer point. This is a narrow but important application that can aid particularly in the reconstruction of port settlements and fortresses, because it allows one to predict a maximum visible radius from important features on the shoreline. The resulting radius can aid researchers in determining at what point land may have been visible for incoming maritime traffic and vice versa. This process is limited somewhat in that the skyline tool, alone, cannot account for a maximum visible radius based on different circumstances. In optimal circumstances, the maximum visible distance for most ground-level human observer is roughly 5 km to the natural skyline due to the gentle curve of the earth (Wickramasinghe 2000: 528). This is somewhat extended when the observer is positioned at a greater height, such as a higher story on a building. In suboptimal conditions, though, such as fog, storm weather, or even glare due to sunlight, the maximum visible radius may be partially or greatly reduced. To that end, the skyline tool may be modified to fit smaller maximum radii, creating a boundary at any visual limit. However, as the tool was not developed to calculate natural obstruction, the radii

distance needs to be known beforehand to input manually into the tool. Such information may be gathered based upon historical documentation or known weather patterns in the region under study. This, in turn, may allow for comparison of visibility during different conditions or even different gradients of the same condition, such as light versus heavy fog. Modifying the skyline tool in this manner can help create a range of comparative lines of visibility which, when used in conjunction with sightlines or other visibility analyses available through both ArcGIS and manual calculations, can aid researchers in tracking when maritime activity would be made visible from land, and when land may have become visible to seamen across potential conditions.

This type of analysis is critically important in understanding the relationship seafaring communities had with port, harbor, and littoral spaces. In spite of the romantics that often accompany seafaring in both the past and present, the end goal of most nautical expeditions was land in some form or another (Blue, Englert, and Hocker 2006: 21). Land meant protection, markets, supplies, provisions, repair, rest, and the opportunity to either claim property or earn money, all of which were limited at sea. This was more true for merchants than almost any other group of seafarers, who often pushed the limits of their ships and supplies to get cargo where it need to go. Sighting land meant a change in all the action onboard a ship, whether it was to act quickly and avoid a treacherous coast or to prepare to navigate in the more confined spaces near land (Taunt 1883: 195). Knowing where this may have started under a range of conditions may offer researchers a more complete understanding of both the shift in actions on inbound ships and the actions or any lack thereof in attempting to save a damaged or wrecked ship.

Visibility Analysis among the Reconstructed Port Royal Buildings

The first set of visibility analyses on the simulated Port Royal buildings were several sets to viewsheds looking at visible ranges from different heights set for each window. The height points for the viewshed were overlaid on the models manually, and thus did not correspond directly to the view from a window, but the view from the window's center height and position on the building. This means that the viewsheds run accounted for both forward and rear window views, rather than a singular view direction. Ultimately, the views included in the overall analysis were those from the second story central windows, or from the westernmost windows if no central window was present on the building.

The Port Royal viewshed analyses are unlike many archaeological viewsheds in that they are not conducted with a high offset from a tall or monumental feature (von Schwerin, Richards-Rissetto, *et al.* 2013: 743; Wheatley and Gillings 2002: 184). Moreover, the data generated from these viewsheds is limited in terms of applicability toward the city. As the city was densely built, presumably incorporating the lower-perspective viewsheds would not offer much information, as the probable view extended no further than across the street. The higher level viewsheds offer more potential information, but without a full city projected as a multi-patch on the reconstructed landmass, the resulting analysis still only applies to the topography of the land. As models for the some 2,000 structures that once stood on the Port Royal tombolo are not present on the reconstructed landmass model, neither the viewshed nor skyline tools can

properly aid in predicting what architectural features would have been visible from the reconstructed buildings. The topographic analysis can, however, provide information about what portions of the city may have had a visual presence from the corner of Lime Street and Queen Street. Assuming that most buildings in Port Royal were no more than three stories in height, with some exception in the forts and the church steeples of the city, the high points on the land can reasonably be thought to correspond with the high points in the city skyline (Hamilton 2006: 16b). The areas cast as visible in the viewshed analyses, then, were presumably areas where the upper stories and rooftops of other city structures may have been visible from within the structures.

To arrive at the viewshed analysis for each structure, first an observer point needed to be established for each building. A number of observer points were tried from both the upper and lower levels of the structures, and observer points on each level of each building resulted in largely the same view, with no more than a meter's difference in lateral change depending upon which window was used as a reference. Due to the increased elevation in observer points set on the second story, the upper window observer points provided a greater range of visible area than the lower windows. Subsequently, the higher observer points were used in order to determine the maximum potential visible yield. For buildings 1 and 5, the second story center window elevation was used. For buildings 2 and 3, the second story westernmost windows were used. Since there was minimal shift in the lateral visibility between windows, a single window was sufficient for viewshed analysis.

With observer points chosen, the desired point for each building was selected in ArcScene and saved as its own layer within the dataset. The “visibility” tool was then run with the reconstructed shoreline raster as the “input raster” and the newly generated observer point for the individual building as the “input point or polyline observer feature.” The “observer elevation” was set to match the z-coordinate of the point, and the tool run to yield a binary viewshed, where one color depicted what topography would have been visible from that point, while the other showed the area that would not have been seen (Conolly and Lake 2006: 231). The resulting viewsheds varied somewhat between each building, but largely yielded the same visible area, suggesting that roughly the same features would have been visible at this intersection.

To provide a better idea of what, exactly, would have been visible from the buildings at the corner of Queen Street and Lime Street, the William Duke of Manchester map was overlaid on each viewshed and made semi-transparent. From this, visible landmarks were taken into account to get an approximate idea of what major features were available from each building. Fort Carlisle, Fort Charles, Fort Morgan, and Fort Rupert were all well out of the view range from the intersection, while Fort James, and a small portion of Fort Walker were within the visible range, as was St. Paul’s Church. Fractions of the area where the King’s House stood would have been visible at different vantages, though hardly any of it was visible from building 3. The greatest lack of visibility from each building was along the southwestern edge of the reconstructed shoreline, as this area sat at a lower elevation than the more visible center of the city. This means that features including the sea wall and the original church structure in the

area now occupied by St. Peter's Church would not have been visible from intersection of Queen Street and Lime Street. Neither, for that matter, would the open Caribbean Sea have been within view of the reconstructed buildings. A small amount of shoreline just north of Fort Morgan does show as visible from the houses, but as this area represents some of the highest land inside the city gates, the taller portions of the land masses may have been visible. It is unlikely, however, that the sea wall or the sea behind it either registered from the opposite side of Port Royal. This may have made major tidal events, including large swells and tidal waves, less detectable from that end of the city.

More practically, though, the close proximity to the wharves, coupled with the gentle downgrading slope toward the waterline, meant that the area along the inner shore, including the wharves, the market, and the Governor's house, would have all likely been visible from the rear windows of the reconstructed structures. This may have provided a visual advantage for merchants that sold imported wares, or that otherwise depended upon the business of sailing merchants or the navy for their livelihood, as they would have been able to more readily see ships coming in on the horizon, allowing them to ready their workers and space to offload, store, and begin sales. This may have been particularly impactful for building 1, as if it housed a pipe shop in rooms five and six, the occupying merchants would have been particularly dependent upon tobacco shipments from Virginia and to a lesser extent some of the other North American colonies (Fox 1998: 79). If the building 4/5 functioned in food service, it may not have expressly needed the business coming off the wharves, but may have also benefitted from a location near to and visible from the area where merchant crew would have

offloaded (Pawson and Buisseret 1974: 113-114). This close proximity to the wharf area may account for how this area in the city, as well as the area behind it on Thames Street became the commercial center of the city (Pawson and Buisseret 1974: 113-114). Stores and commercial services in the area may have benefitted greatly both from their ability to see and to be seen from the commercial waterfront lining Kingston Harbor.



Figure 7.1: Binary viewsheds for building 1 (top left), building 2 (top right), building 3 (bottom left), and building 4 (bottom right). All visible area is represented in blue, and non-visible area represented in gray.

Port Royal Skyline Analysis

While viewshed analysis provided insight into what would have been visible from shore, a modified application of the “skyline” tool allows for estimations of when Port Royal, as a landmass, may have become visible from sea. By using the analysis tool to project a radius out from the landmass toward the sea, the maximum distance at which Port Royal was visible to the naked eye from incoming ships may be ascertained. As with the viewshed analyses, the skyline analyses warrant critique in that they do not account for the rise of the city’s buildings. The increased height provided by the structures on the landmass may have slightly lengthened the range at which Port Royal was visible. However, as most structures in the area sat at around two or three stories, there would have been some impact on visibility, but not enough to drastically extend the ranges produced by the current analysis.

As with the viewsheds, the skyline analyses were conducted directly in ArcScene. The tool was run four times, once each from the observer points established for the viewsheds. No input surface was used, as that would have restricted the tool to just the Port Royal landmass, rather than the area surrounding it. The only modification made to the tool aside from input and output was the maximum horizon radius under the “Skyline Options” expandable field. This was set to five kilometers, the range at which the earth curves just slightly out of visible distance

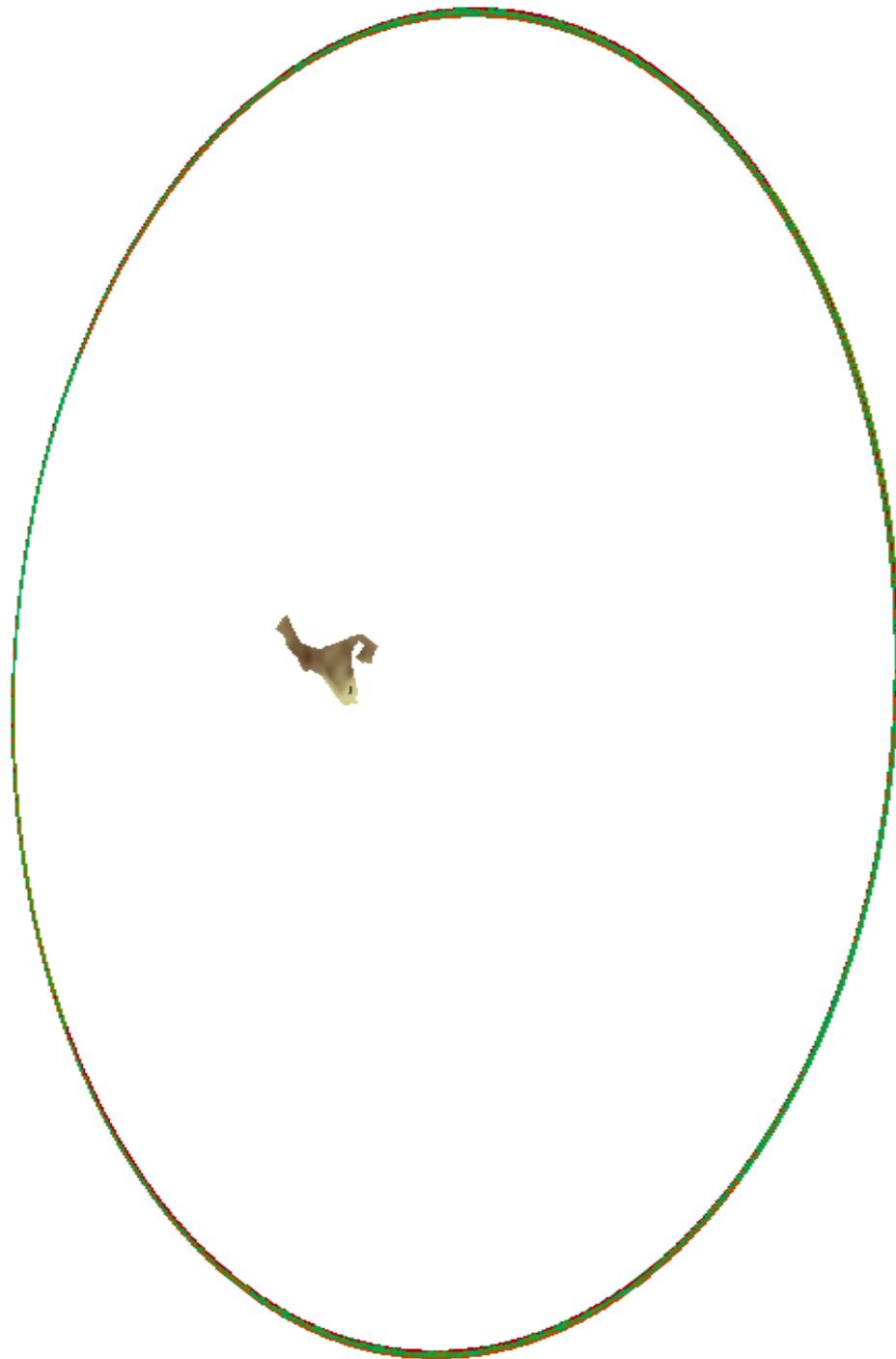


Figure 7.2: An overlay of all skyline horizons out to 5 km for building 1-5

(Wickramasinghe 2000: 528). The tool was run for each observer point, and produced a 5km radius around the observer point. The resulting skylines showed when the reconstructed buildings, specifically, rather than the shoreline, in general, would have been visible from the sea. Within ArcScene, there was little visible differentiation between the extents of the skyline radii (Figure 7.2). However, at full scale they would vary by one to a few meters due to separation between the structures. Additionally, an observer point was generated at the extreme southern tip of the landmass to project the furthest possible distance at which Port Royal may be observed at deck level by the naked eye.

For the Port Royal analyses, little modification was made to account for structure height as the distribution of shorter and taller structures throughout different points in the city is not currently backed by either archival or archaeological evidence. Likewise, no modifications were made to the maximum visible radius as no single atmospheric event is under consideration. However, the inputs in the tool may be readily modified to create more exact data. A more exact maximum radius may be calculated factoring in height of the largest major structure on the landmass and its rise above the natural horizon (Conolly and Lake 2006: 228-229). Likewise, for even more precise calculations, if a researcher is investigating a specific vessel with a known weather deck height, the skyline may be further adjusted to account for the offset of the elevated point within the radius. Archival evidence coupled with basic atmospheric data could aid in creating an estimated range of visibility limits due to inclement weather or storm conditions. In the case of the Port Royal reconstructions, no one specific account was being investigated,

but modification of the tool did allow for a maximum forecasted range of visibility from each building, as well as the extremity of the city.

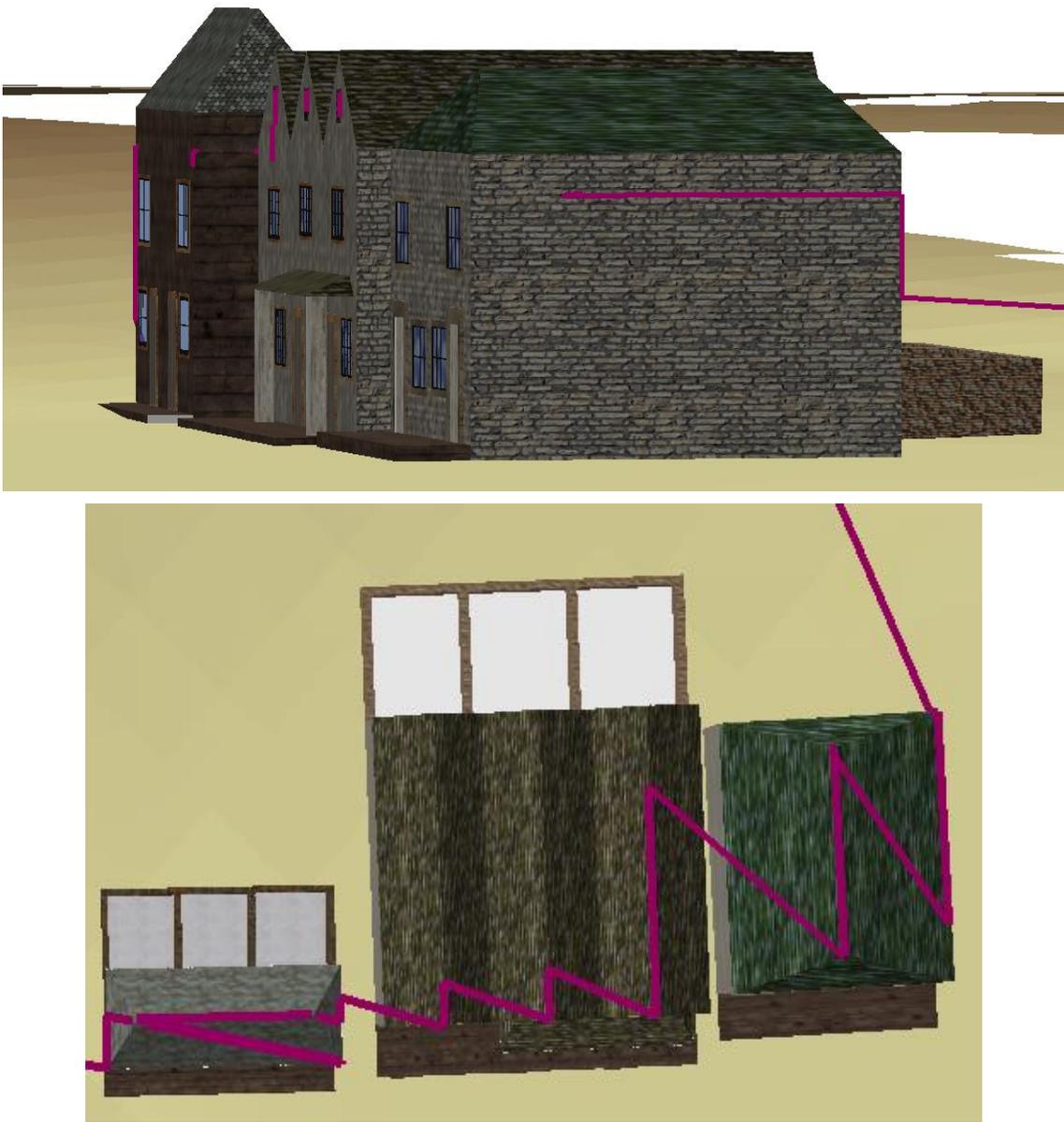


Figure 7.3: The skyline (purple) generated from the top left window of Building 4/5 as seen from window level (top) and from above (bottom). The purple line depicts the line of obstruction to the horizon line (in blue). Facing the street, everything inward of the purple line depicts the visual obstructions from the observer point.

The skyline tool, moreover, can work closer to its designed function when used with an observer point on land. A skyline was created from the building 4/5 complex using the same observer point as the first analysis. However, the other three buildings were added into this analysis as “input features.” The resulting line created visual breaks where the reconstructed building would have obscured observers in building 4/5 from seeing directly outward to the limit of the horizon (Figure 7.3). From there, a multipatch was generated showing the extent of the visible range out to the limit of the horizon, but accounting for the visual impediment of the other reconstructed buildings. The scripted purpose of the skyline tool is, indeed, to generate a line of demarcation where the ground features meet the sky from a given observer point (Guney, Girginkaya, *et al.* 2012: 171). By using the skyline tool to factor in three dimensional features when forecasting visibility in a harbor or port area, researchers can create a more exact idea of what areas were and were not visible from given points of interest. It may help them determine the range of visibility from major structures such as lighthouses, bridgehouses, or any number of shipyard structures. It may also provide an idea of at what range individuals on shore would reasonably be able to see incoming maritime traffic. This may be useful especially for military purposes, as it can provide an observable point at which a fortress moves from preparation into the active stage of defense or battle with a sea-based opponent. If historical documentation is able to provide information about the rough speed of the incoming vessels, one could even calculate how much time those on land had before the ship was close enough to reasonably fire upon. This may also be useful when looking at the relationship between the development of merchant space and the

development of wharf or quay space. While it stands to reason that merchant space dependent upon goods arrived on ships would be close to the areas where the ships dock, visibility may help further determine why certain areas proximal to the shoreline were favored over others, as some regions may have provided better visible access to the incoming resources, enabling all parts of trade-based commercial enterprises to more readily interact.

Assessing the Skyline Tool Application

As the skyline tool was not designed for use projecting across maritime environments, its application in this area is still under development. However, when considering the critical relationship that sight had in nautical navigation, and the relationship between ship and shore, the skyline tool proves its worth in its ability to forecast visibility between an observer point and points on the horizon. When coupled with viewshed analyses, these tools provide a comprehensive set of visible ranges from a port city, as demonstrated here with the Port Royal analyses. When coupled, the viewshed and skyline analyses show what portions of the city may have been visible from each of the reconstructed buildings, both on land and across the maximum, unadjusted visible radius at sea. This, in turn, may offer better perspective as to interactions between vessels and land-based enterprises, both commercial and military.

CHAPTER 8

CONCLUSION

The loss of Port Royal was a sudden, catastrophic event that forever changed the English Caribbean. Lost to an earthquake in 1692, the “wickedest city on earth” was gone but not forgotten, and when its remains emerged during archaeological excavation, the city-that-was was, for the first time in three centuries, connected back to the history of Jamaica and the English colonial world.

Investigating Port Royal through GIS analysis and three-dimensional reconstruction of the excavated structures brought some life back into the lost city. Historical maps and iconography provided the basis for the reconstruction, showing the probable shape and extent of the area as it would have looked prior to destruction. Georeferencing those images allowed for the creation of an averaged line to represent the historical shoreline. The shoreline was then filled in using current elevation data along with bathymetry. In this way, it was possible to recreate an approximation of the pre-earthquake landmass, shifting the archaeological data from the seabed back to its harbor side location, and creating a data-driven representation of the landmass’ probable shape and appearance in early 1692. Further work still needs to be undertaken in this area, though, specifically to address the process of determining probable elevations of sunken landscapes. While such was outside the realm of this project, interdisciplinary efforts involving oceanography, geology, geography, and archaeology may provide better insight into the process of raising sunken areas such as Port Royal.

Integrating 3D models of the excavated buildings into the GIS allowed for both visual representation and extended analysis of the area. Using viewshed and skyline analyses, both native to the ArcGIS software, the visual significance of the reconstructed buildings relative to both the landmass and incoming vessels could be established. The area at the corner of Queen Street and Lime Street was, based off the combined visual analyses, a well-chosen space in which to establish commercial enterprise. Its height above the harbor shoreline provided it with both proximity to and visual significance from the merchant entry into the town. The area would have been nearby, visible, and easily accessible for ships landing and offloading both people and goods in the city.

The adoption of such analyses into archaeological data expands the potential application of 3D reconstructions, which have become common but remain largely an aesthetic tool in the discipline. Working within the confines of ArcGIS 10, this project was able to look at what data could be easily extracted from a model, and what had to be stored elsewhere and linked within the GIS. This aids in the understanding of the current limitations of 3D analysis from reconstructed models, and helps to not only set protocol for such analyses, but outline goals for future adaptations of 3D geospatial technology. It moreover looked at adaptive methods of using standard tools within the ArcGIS software suite, making use of visualization and 3D analysis tools that have previously not had a home in archaeological research. In doing so, this project served to establish the usefulness of the skyline tool, and further to extend the potential of GIS-based archaeological analysis beyond simple data storage and viewshed analysis. Other such work is well underway in the field, and this project builds upon the established

knowledge of 3D analysis in GIS to examine new potential in how analytical tools may be applied to a reconstructed site, as well as the process of raising a previously submerged site in a constrained and meaningful way.

Port Royal's submergence was an unquestionably tragic event, and one that would shape English presence in the Caribbean from that moment moving forward. The vertical sinking due to liquefaction, though, has provided archaeologists with an unparalleled understanding of the city as it existed before catastrophe. Reconstructing the submerged site works to further that archaeological information, establishing not just the material remains but the landmass, itself, and commanding presence of the city constructed on top of it. Digital reconstruction at this point is partial and needs more data to continue, but represents the start of reconstructive efforts to contextualize archaeological data within the geography that was Port Royal.

REFERENCES

- Abdul-Rahman, A., Zlatanova, S. and Coors, V., 2006, *Innovations in 3D Geo Information Systems*. Berlin: Springer.
- Allsworth-Jones, P., 2008, *Pre-Columbian Jamaica*. Tuscaloosa: University of Alabama Press.
- Atkinson, L., 2006, *The Earliest Inhabitants : The Dynamics of the Jamaican Taino*. Kingston: UWI Press.
- Barlow, E. "Port Royal, Jamaica" [Manuscript]. National Maritime Museum, Greenwich, London. 1659-1703.
http://collections.rmg.co.uk/collections/objects/505786.html?_ga=2.31849015.865122882.1493945883-834849779.1493928858
- Brimicombe, A., 2003, *GIS, Environmental Modelling and Engineering*. Boca Raton: CRC Press.
- Buisseret, D., 2006, Urbanization in the Old World and in the New, in S. G. Reinhardt, D. Reinhartz (eds.), *Transatlantic History*. College Station: Texas A&M University Press.
- Buisseret, D., 1980, *Historic Architecture of the Caribbean*. London: Heinemann.
- Carrara, A., Bitelli, G. and Carla, R., 1997, Comparison of Techniques for Generating Digital Terrain Models from Contour Lines, *International Journal of Geographical Information Science* **11**: 451-73.

- Clifford, S. A., 1993, *Analysis of the Port Royal Shipwreck and its Role in the Maritime History of Seventeenth-century Port Royal, Jamaica*. MA Thesis, Department of Anthropology, Texas A&M University.
- Conolly, J. and Lake, M., 2006, *Geographical Information Systems in Archaeology*. Cambridge: Cambridge University Press.
- Crain, E. E., 1994, *Historic Architecture in the Caribbean Islands*. Gainesville: University Press of Florida.
- Darrington, G. P., 1994, Analysis and Reconstruction of Impermanent Structures of the 17th and 18th Centuries. MA Thesis, Department of Anthropology, Texas A&M University
- Dell'Unto, N., Landeschi, G., Leander Touati, A., Dellepiane, M., Callieri, M. and Ferdani, D., 2016, Experiencing Ancient Buildings from a 3D GIS Perspective: a Case Drawn from the Swedish Pompeii Project, *Journal of Archaeological Method and Theory* **23**: 73-94.
- Domingo-Santos, J. M., de Villarn, R. F., Rapp-Arrars, g. and de Provens, E. C., 2011, The Visual Exposure in Forest and Rural Landscapes: An Algorithm and a GIS Tool, *Landscape and Urban Planning* **101**: 52-8.
- Fox, G. L., 1998, The Study and Analysis of Kaolin Clay Tobacco Pipe Collection from the Seventeenth-Century Archaeological Site of Port Royal, Jamaica, PhD Dissertation, Department of Anthropology, Texas A&M University
- Garcia, A. C. A., 2017, New ports of the New World: Angra, Funchal, Port Royal and Bridgetown, *International Journal of Maritime History* **29**: 155-74.

- Gravette, A. G., 2000, *Architectural Heritage of the Caribbean: an A-Z of Historic Buildings*. Kingston: Ian Randle.
- Gregory, I. N. and Ell, P. S., 2007, *Historical GIS*. Cambridge: Cambridge University Press.
- Guney, C., Akdag Girginkaya, S., Cagdas, G. and Yavuz, S., 2012, Tailoring a Geomodel for Analyzing an Urban Skyline, *Landscape and Urban Planning* **105**: 160-73.
- Hamilton, D., 2017 The Port Royal Archives.
<http://nautarch.tamu.edu/portroyal/archives/index.htm>
- Hamilton, D., 2008, Port Royal, Jamaica: Archaeological Past, Present, and Future, in Keshikar-Denton, M., and Erreguerena, P. L., (eds.). *Underwater and Maritime Archaeology in Latin America and the Caribbean*: 259-69. Walnut Creek: Left Coast Press.
- Hamilton, D., 2006, Pirates and Merchants: Port Royal, Jamaica, in R. K. Skowronek, in C. R. Ewen (eds.), *X Marks the Spot: the Archaeology of Piracy*, 13-30. Gainesville: University Press of Florida.
- Hamilton, D., 2005, Resurrecting 'The Wickedest City in the World': Port Royal, Jamaica, Beneath the Seven Seas, Adventures with the Institute of Nautical Archaeology. New York.
- Hamilton, D., 1988, Underwater Excavations of 17th-Century Building at the Intersection of Lime and Queen Streets, *Underwater Excavations of 17th-*

- Century Building at the Intersection of Lime and Queen Streets, in Delgado, J., (ed.) *Society for Historical Archaeology Conference*, 9-12. Reno.
- Harvey, D., 2006, *Spaces of Global Capitalism: A Theory of Uneven Geographical Development*. London: Verso.
- Heath, E., Rev., fl. 1692, *A full account of the late dreadful earthquake at Port Royal in Jamaica written in two letters from the minister of that place : from a board the Granada in Port Royal harbour, June 22, 1692*. London : Printed for Jacob Tonson, and sold by R. Baldwin.
- Heidtke, K. P., 1992, *Jamaican Red Clay Tobacco Pipes*. MA Thesis, Department of Anthropology, Texas A&M University
- Hill, L. L., 2006, *Georeferencing: the Geographic Associations of Information*. Cambridge: The MIT Press.
- Johnson, D., 2000, *Port Royal, Jamaica and the Slave Trade*. MA Thesis, Department of Anthropology, Texas A&M University.
- Kemp, K. K., 2008, *Encyclopedia of Geographic Information Science*. Los Angeles: Sage.
- Kritzler, E., 2008, *Jewish Pirates of the Caribbean*. New York: Doubleday.
- Llobera, M., 2003, Extending GIS-based Visual Analysis: The Concepts of Visualscapes, *International Journal of Geographical Information Science* **17**: 25-48.

- “Londinium Feracissimi An Gliae Regni Metropolis” [Map]. National Maritime Museum, Greenwich, London. 1580.
<http://collections.rmg.co.uk/collections/objects/149863.html>
- Low, S. M., 2009, Towards an Anthropological Theory of Space and Place, *Semiotica* **2009**: 21-37.
- Martínez Fernández, L., 2015, Far beyond the Line: Corsairs, Privateers, Buccaneers, and Invading Settlers in Cuba and the Caribbean (1529-1670), *Revista de Indias* **75**: 7-38.
- Maunder, C. J., 1999, An Automated Method for Constructing Contour-based Digital Elevation Models, *Water Resources Research* **35**: 3931-40.
- Maudlin, D. and Herman, B. L., 2016, *Building the British Atlantic World*. Chapel Hill: University of North Carolina Press.
- McCoy, M. D. and Ladefoged, T. N., 2009, New Developments in the Use of Spatial Technology in Archaeology, *Journal of Archaeological Research* **17**: 263-295.
- Meyers, A. D., 1999, West African Tradition in the Decoration of Colonial Jamaican Folk Pottery, *International Journal of Historical Archaeology* **3**: 201-23.
- Mintz, S., Houses and Yards Among Caribbean Peasantries, in Philip Scher (ed.) *Perspectives on the Caribbean: A Reader in Culture, History and Representation*, 9-24. Hoboken: Wiley-Blackwell.
- Mulcahy, M., 2008, The Port Royal Earthquake and the World of Wonders in Seventeenth-Century Jamaica, *Early American Studies* **6**: 391-421.

- Nelson, L., 2016, *Architecture and Empire in Jamaica*. New Haven: Yale University Press.
- Nutsford, D., Reitsma, F., Pearson, A. and Kingham, S., 2015, Personalising the Viewshed: Visibility Analysis from the Human Perspective, *Applied Geography* **62**: 1
- Oldmixon, M., 1708, *The British empire in America : containing the history of the discovery, settlement, progress and present state of all the British colonies on the continent and islands of America ... With curious maps done from the newest surveys*. London: Printed for John Nicholson.
- Ormsby, T., 2008, Getting to Know ArcGIS Desktop: Basics of ArcView, ArcEditor, and ArcInfo. Redlands: ESRI Press.
- Pacina, J., Novak, K. and Weiss, L., 2011, 3D Modelling as a Tool for Landscape Restoration and Analysis, in Hiebicek, J., and Schimak, G., (eds.) *International Symposium on Environmental Software Systems*, 123-38. Berlin: Springer.
- Pawson, M. and Buisseret, D., 1975, *Port Royal, Jamaica*. Kingston: UWI Press.
- Pestana, C. G., 2017, *The English Conquest of Jamaica : Oliver Cromwell's Bid for Empire*. Cambridge: Harvard University Press.
- Pickles, D., McCaig, I. and Wood, C., 2017, *Traditional Windows*. London: Historic England.
- Pipkin, B. W., Hazlett, R. W., Trent, D. D. and Bierman, P., 2010, *Geology and the Environment*. Belmont: Brooks/Cole.

- “Plano de Puerto Real en la Ysla Jamaica” [Manuscript]. La Biblioteca Nacional de España. 18th Century. <http://bdh.bne.es/bnearch/detalle/bdh0000032257>
- Rodman, M. C. 1992, Empowering Place: Multilocality and Multivocality, *American Anthropologist* **94**: 640-56.
- Saint, A., 2010 Obituary: Oliver Cox: Influential and Creative Postwar Architect with a Sharp Eye for the Social Dimension 2010, *The Guardian*: 34.
- Saldana, M., 2015, An Integrated Approach to the Procedural Modeling of Ancient Cities and Buildings, *Digital Scholarship in the Humanities* **30**: i163.
- Savitsky, B. G. and, Lacher, T. E., 1998, *GIS Methodologies for Developing Conservation Strategies: Tropical Forest Recovery and Wildlife Management in Costa Rica*. New York: Columbia University Press.
- Schofield, J., 1987, *The London Surveys of Ralph Treswell*. London: London Topographical Society
- Sheppard, S. R. J. and Cizek, P., 2009, The Ethics of Google Earth: Crossing Thresholds from Spatial Data to Landscape Visualisation, *Journal of Environmental Management* **90**: 2102-17.
- Smith, C. W., 1995, *Analysis of the Weight Assemblage of Port Royal, Jamaica*. PhD Dissertation, Department of Anthropology, Texas A&M University.
- Tang, X., Lou, Y., Ye, F., Yan, X., 2016, Research of Constructing 3D Digital River Based on ArcEngine and SketchUp in Jing, W., Peng, S., Che, W., Wang, H., Lin, J., Sun, G., Song, X., Han, Q., Lu, Z. and Song, H., (eds.) *Social Computing:*

- Second International Conference of Young Computer Scientists, Engineers and Educators*, Harbin, China, August 20-22, 2016, Proceedings, Part II.
- Tilley, C., 2010, *Interpreting Landscapes: Geologies, Topographies, Identities; Explorations in Landscape Phenomenology 3*. Walnut Creek: Left Coast Press.
- Taunt, E. H., 1883, *Young Sailor's Assistant in Practical Seamanship : Including the Rules of the Road; Directions for Resuscitating the Apparently Drowned, etc., etc., Together with the Salutes ... Naval Signal Flags, Very's Lights, and the International Code of Signals*. Washington D.C: Navy Department.
- Taylor, J., 1886, *Second Part of the Historie of His Life and Travels in America*. Kingston: Institute of Jamaica.
- Tomlinson, R. F., 2013, *Thinking About GIS: Geographic Information System Planning for Managers*. Fifth edition. Redlands: ESRI Press.
- Trussell, T. D., 2004, *Artifacts of Ambition: How the 17th-Century Middle Class at Port Royal, Jamaica, Foreshadowed the Consumer Revolution*. MA Thesis, Department of Anthropology, Texas A&M University.
- von Schwerin, J., Richards-Rissetto, H., Remondino, F., Agugiaro, G. and Girardi, G., 2013, The MayaArch3D Project: A 3D WebGIS for Analyzing Ancient Architecture and Landscapes, *Literary and Linguistic Computing* **28**: 736-53.
- Waters, A. M., 2006, *Planning the Past*. Lanham: Lexington Books.
- Wells, A. E., *Virtual Reconstruction of a Seventeenth-Century Portuguese Nau*. MA Thesis, Department of Anthropology, Texas A&M University.

Wheatley, D., 2004, Making Space for an Archaeology of Place, *Internet Archaeology*

15.

Wheatley, D. and Gillings, M., 2002, *Spatial Technology and Archaeology*. London:

Taylor & Francis.

Wheatley, D. and Gillings, M., 2000, Vision, Perception and GIS: Developing Enriched

Approaches to the Study of Archaeological Visibility, In, Lock, G. (eds.) *Beyond the map: Archaeology and Spatial Technologies*. Amsterdam: IOS Press.

Wickramasinghe, T., 2000, Estimating the Distance to the Horizon, *The Physics Teacher*

38: 528.

Yang, Q. H., Snyder, J., and Tobler, W., 2000, *Map Projection Transformation:*

Principles and Applications. New York: CRC Press.

Zahedieh, N., 1986, The Merchants of Port Royal, Jamaica, and the Spanish Contraband

Trade, 1655-1692, *The William and Mary Quarterly* **43:** 570-93.

APPENDIX I GEOREFERENCED MAPS

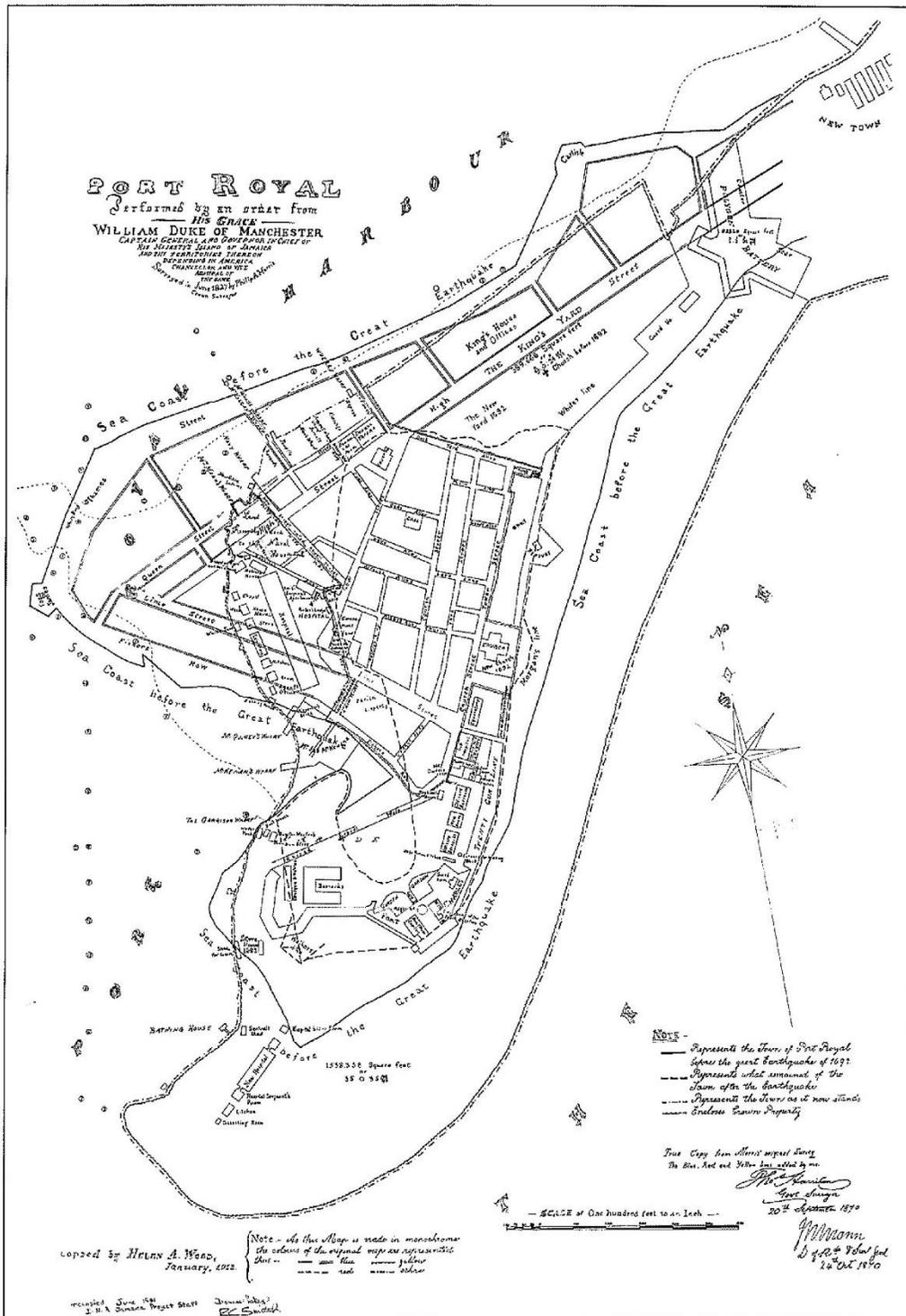


Figure 9.1: William Duke of Manchester Map

Morris, P.A., "Port Royal, Jamaica, before and after the earthquake of 1692"
 [Map]. London, England : British National Archives [MFQ 1/931]. 1827.



Figure 9.3: 1683 map of Port Royal by William Hack of London's Mapping School
Hack, W., "Map (part only) by William Hack, a map maker of London's Mapping School" [Map]. 1683. <http://nautarch.tamu.edu/portroyal/archives/Map1.htm>



Figure 9.4: Bathymetric data from submerged area of the old city (Hamilton 2017)

APPENDIX II CONTOUR CREATION AND ELEVATION DATA



Figure 9.5: DEM of southeastern Jamaica

The ASTGDEMV2_0N17W077 was retrieved from the online Earth Explorer, courtesy of the NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, <https://earthexplorer.usgs.gov/>.

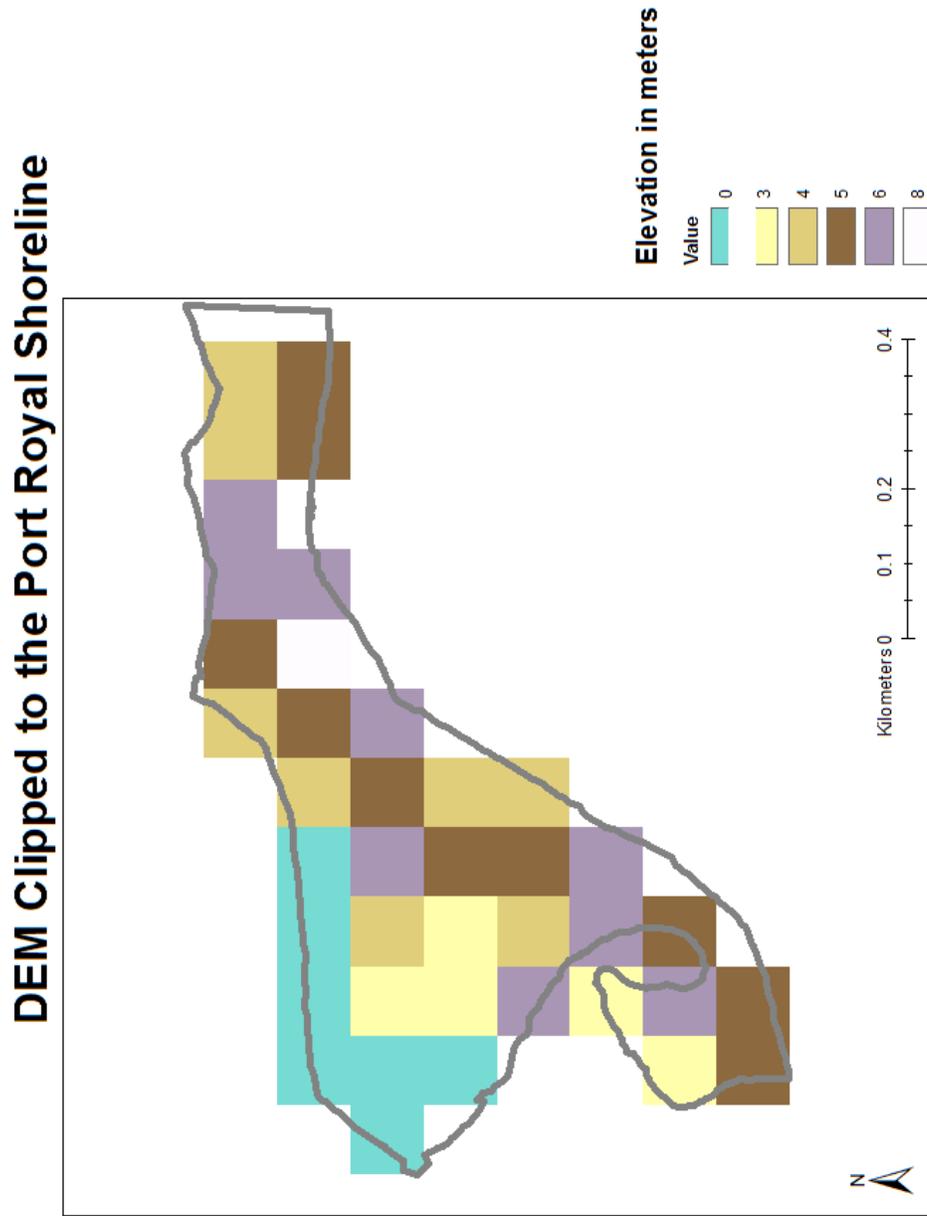


Figure 9.6: Map depicting the DEM after being clipped to the Port Royal shoreline

Contours Extracted from the DEM

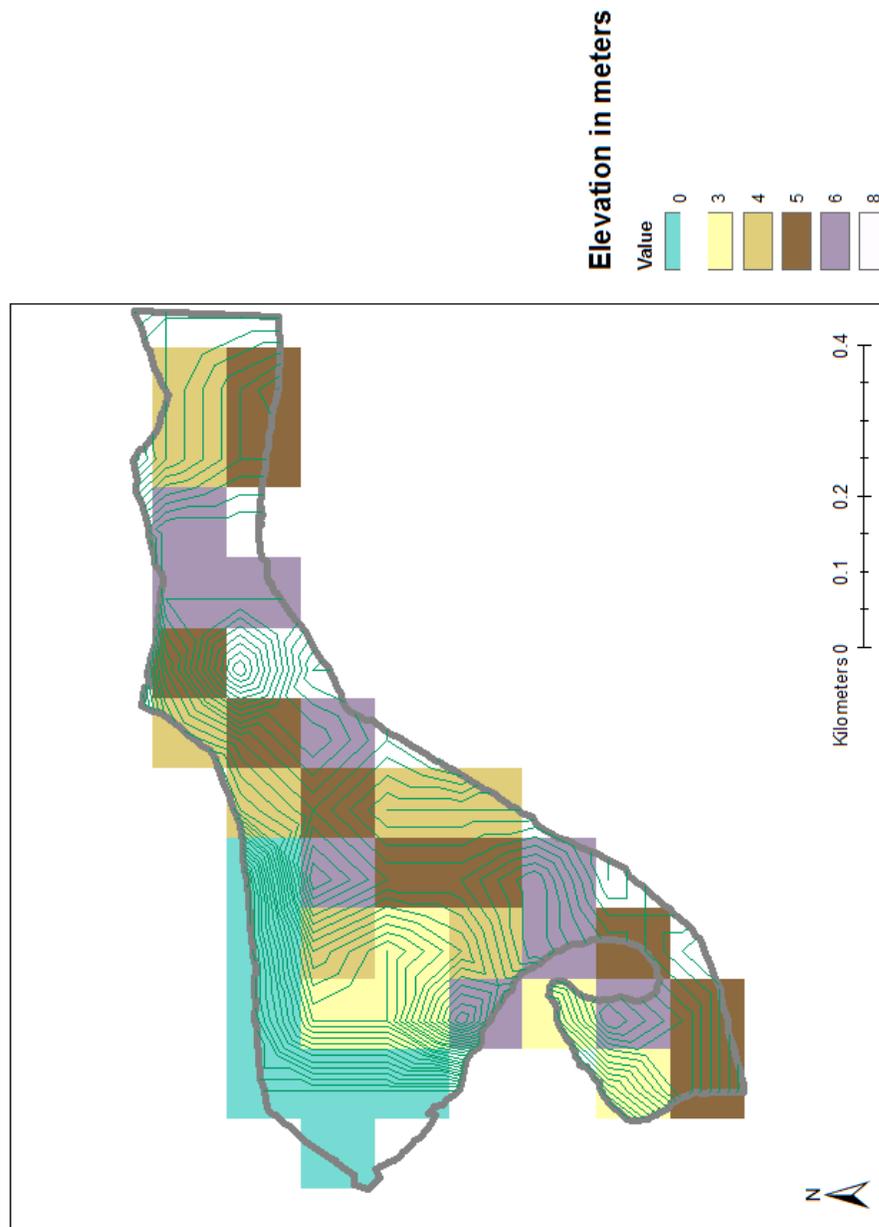


Figure 9.7: Contour lines extracted from the DEM

Contours Created from Bathymetric Data

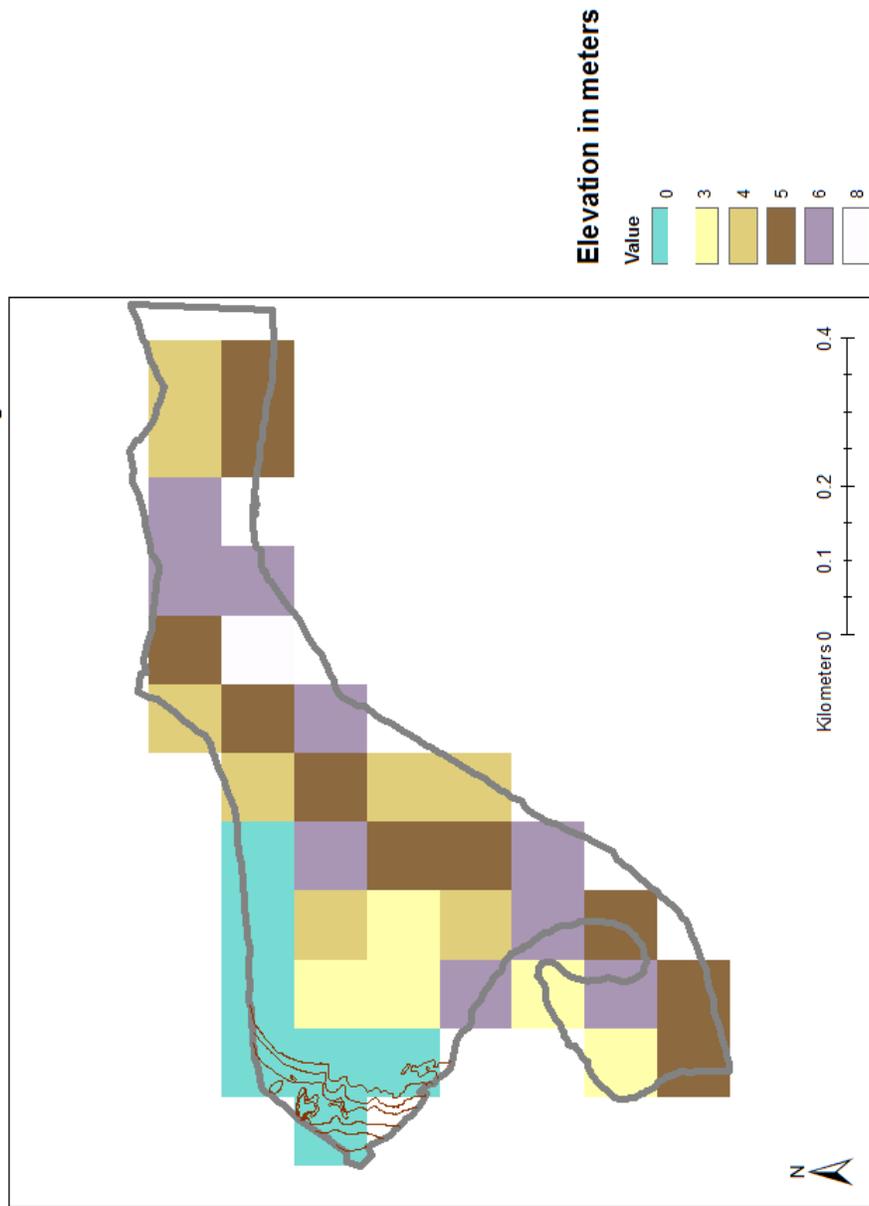


Figure 9.8: Contour lines created from the bathymetric data of the submerged site

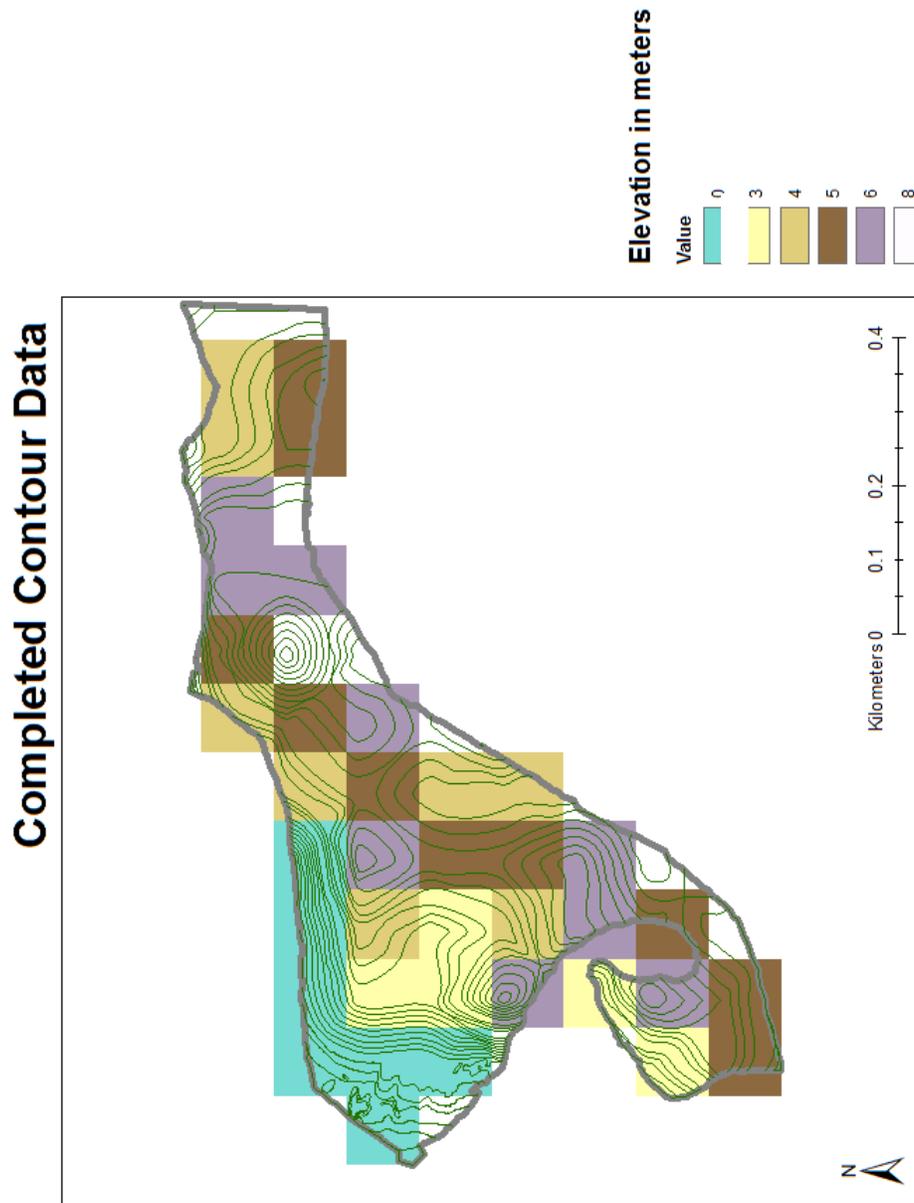


Figure 9.9: Fully integrated and smoothed contour data

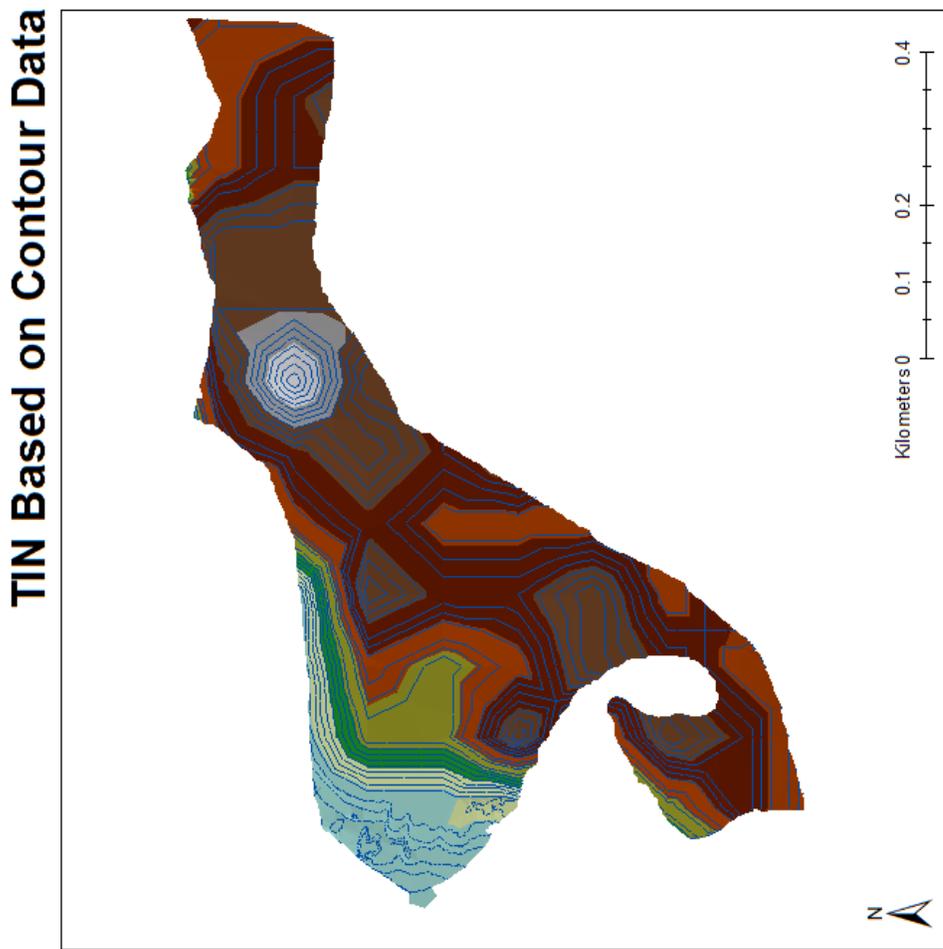


Figure 9.10: TIN generated based on the contour data

DEM Created Based on TIN Values

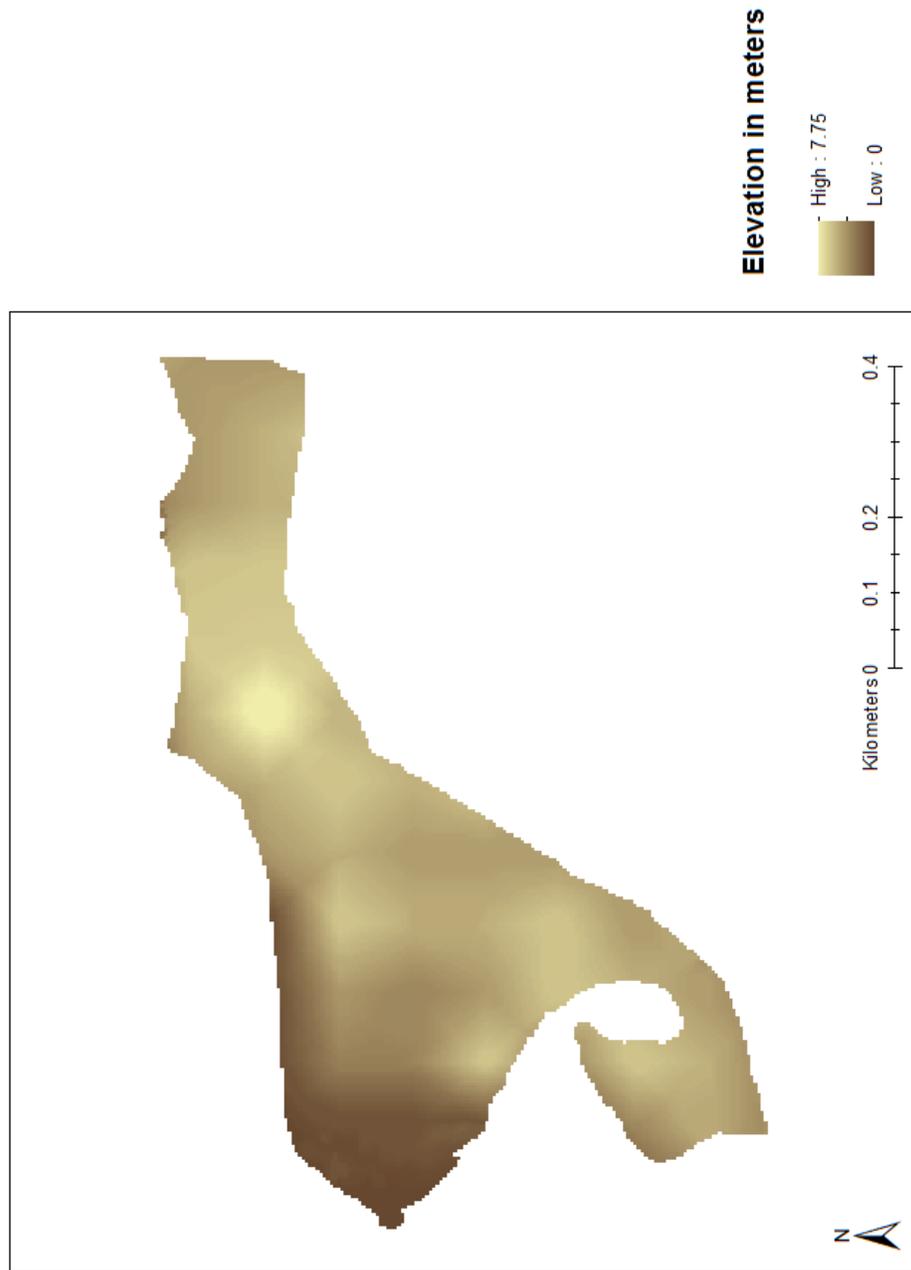


Figure 9.11: The final DEM of old Port Royal based on the TIN data

APPENDIX III RECONSTRUCTED BUILDING MODELS



Figure 9.12: Elevation of the Building 1 reconstruction



Figure 9.13: Perspective view of the front of Building 1 reconstruction



Figure 9.14: Overhead view of the Building 1 reconstruction



Figure 9.15: Elevation of the Building 2 reconstruction



Figure 9.16: Perspective view of the Building 2 reconstruction

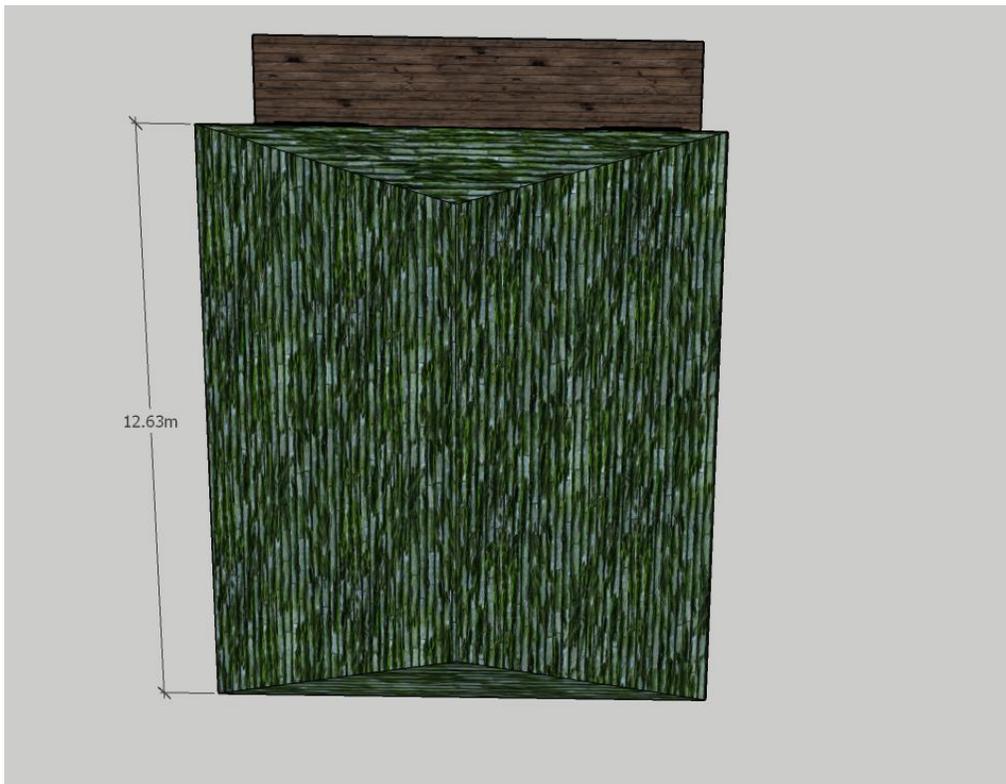


Figure 9.17: Overhead view of the Building 2 reconstruction



Figure 9.18: Elevation of the Building 3 reconstruction



Figure 9.19: Perspective view of the Building 3 reconstruction



Figure 9.20: Overhead view of the Building 3 reconstruction



Figure 9.21: Elevation of the Building 4/5 reconstruction



Figure 9.22: Perspective view of the Building 4/5 reconstruction

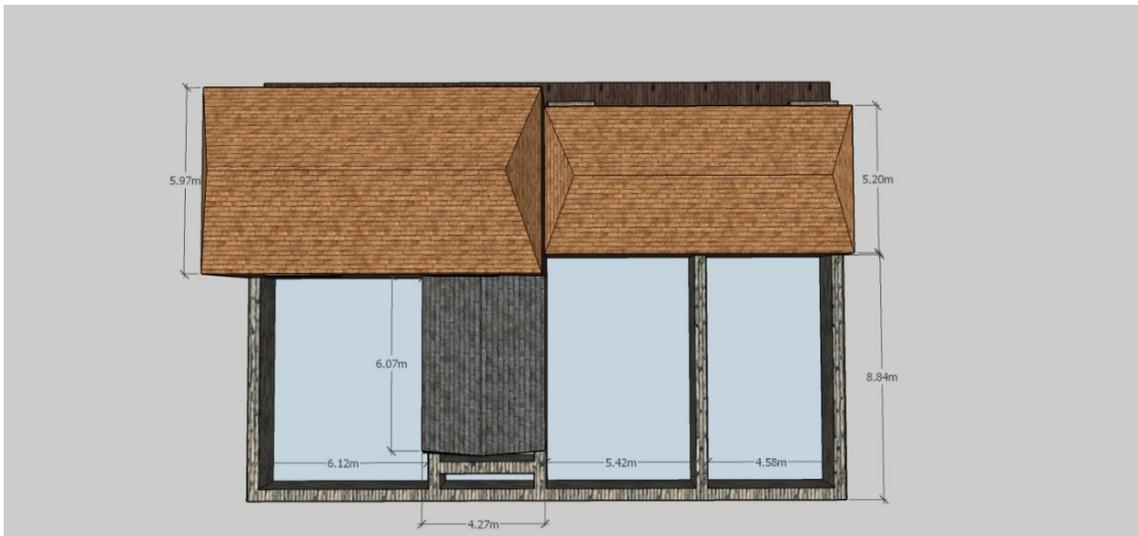


Figure 9.23: Overhead view of the Building 4/5 reconstruction