Abstract

Remote, extreme settlements often depend on an equally extreme dedication of resources and planning to achieve their goals, whether geopolitical, scientific, extractive or otherwise. This thesis uncovered pitfalls of these settlements, adding to the existing literature through a critical analysis of McMurdo Station, Antarctica. McMurdo exists as the logistical hub for the U.S. Antarctic Program, supporting the science activities on the continent. The remoteness and severity of the environment, combined with the numerous, well-documented failures of planning, have resulted in an operationally inefficient and substantially improvable station.

This study adopts a mixed methods approach unique among planning methodologies, incorporating interviews of involved planners, scientists, and analysts, available planning documents and literature, and a Building Information Model (BIM) to qualitatively and empirically analyze the station planning and resulting design. This study found that remote, extreme settlements must critically balance their budgets, personnel, and resources in order to engender effective, contextual, local planning practices necessary to respond to the needs of the settlement. In the case of McMurdo, competing budget elements took priority over sustained planning efforts, capital investment and maintenance of the station, all of which contributed to a substantial breakdown between planning and station development. Additionally, the resulting cascade of planning failures evident at McMurdo suggests extreme settlements are a form of urbanism subject to the same planning needs and failures of more standard subjects of urban planning.
Table of Contents

Chapter 1: The Groundwork                    5
  Background                                   5
  Literature Review                             11
  Methodology                                   21

Chapter 2: Planning and Development of McMurdo Station       27
  Master Planning Chronology, Priorities, Successes and Failures  27
  Analysis of planning and development of McMurdo                  40
  McMurdo Station Built Environment and Design                    46

Chapter 3: Analysis of McMurdo’s Master Planning and Resulting Built Environment   48
  Testing the Priorities of Master Plans and Station Conditions           48
  Principal BIM Findings                                                 56

Chapter 4: Conclusions                             57
  Why did planning fail to produce a high-quality built environment for McMurdo Station?  57
  Planning Practices                                                   58
  Conclusions                                                        65
  Bibliography                                                       70
Chapter 1: The Groundwork

Background

Urban-scale settlements have been developed in remote and extreme conditions across the globe. The nature and impetus for these settlements vary: some settlements were claimed land and developed under the auspices of imperialism; others were industry related; many serve the purpose of science. These remote settlements face unique challenges due to their location and environmental conditions (Fichter, 2008). For example, Edinburgh of the Seven Seas is a village located on Tristan de Cunha, an island roughly halfway between South America and South Africa. The approximately 247 islanders are governed as part of the British overseas territory St. Helena, and the main industry is shellfish fishing. The inhabitants of this island were evacuated and returned after a volcanic eruption in 1961-63, and sustained severe damage from a hurricane in 2001; support from abroad helped rebuild the village after both disasters (Encyclopedia Britannica, 2018). The location and environment of settlements such as these may impact the process through which each of these settlements is planned; determining the level of significance and impact of these constraints is the more difficult question and the aim of this thesis. This research aims to explore salient issues for settlements of this type, identifying causes of these issues through research of relevant topics inclusive of planning, development, operations, maintenance, economics and funding, relationship to mother country, and others, and attempt to determine the significance of each cause in relation to the settlements’ unique challenges.

Tristan de Cunha serves as one of several secondary case studies of this thesis; McMurdo Station, Ross Island, Antarctica (refer to Figure 1) was identified as the most remote and
environmentally severe urban-scaled settlement on the planet and serves as the primary case study. According to the U.S. Antarctic Program Blue Ribbon Panel (2012):

Antarctica is the coldest, driest, windiest, most remote, highest (on average), darkest (for half the year) continent on Earth. Temperatures as low as –128.6°F (–89.2°C) and wind speeds of 154 miles per hour (248 kilometers per hour) have been recorded. (p. 13)
Despite the severe environment, McMurdo Station continues to functionally support logistical and scientific operations. McMurdo is operated by the U.S. Antarctic Program under the National Science Foundation, and consists of approximately 100 buildings on 49 acres, hosting approximately 1100 people in the summer and 200 more-permanent residents in the winter. McMurdo serves as the logistical hub for the many smaller stations across Antarctica (Figure 2); it is the “portal” to other stations and field sites. A common metaphor for McMurdo Station is that of an iceberg: approximately nine times as much resources are expended for the logistical support of the science that takes place there, akin to the nine-to-one ratio of an iceberg’s mass below and above the waterline (Blue Ribbon Panel, 2012).

Figure 2. McMurdo Station, Antarctica. Reinhart Piuk, Antarctic Photo Library.
Often referred to as a hybrid military base, college campus, and mining town, McMurdo incorporates diverse services (Davis, 2017). From medical bay to machine shop, the range of enterprises supporting life and science are critical and self-reliant in their day-to-day activity, largely out of multifaceted necessity. A prolonged budget cycle combined with one of the world’s longest supply chains results in a delay of materials, parts or other resources of up to two years after the need is determined. Additionally, single-point failures are identified as elements of a system that, upon failure, result in the system breaking down entirely. For McMurdo Station, these range from uncertain icebreaking capabilities from an aging fleet to fire suppression systems that run on electric power with inadequate backups. According to the Blue Ribbon Panel (2012), nine single-point failure situations were identified during their analysis of McMurdo and other USAP stations. The foresight needed to conduct activities in Antarctica is compounded by these challenges, especially the remoteness of the station and the severity of the environment.

Scientific inquiry and advancing industry continue to suggest the possibility of ever-more-extreme settlements. McMurdo’s combined self-reliance, prolonged budgeting cycle, vulnerability to single-point failures, remoteness and extreme environment engender an analog to future colonization of the solar system (Carroll, 2019). A similar view of McMurdo was found with Davis (2017):

As with space travel, being in Antarctica is something humans can only do with great effort and logistical support, for the landscape, while striking, is both desolate and unforgiving. The same beauty captured in countless photographs over the last century can be a dangerous distraction from the fact that, if cut off from outside world, people face grim prospects and no chance of long-term survival. (p. 167)

McMurdo Station stands as the most urban-scaled settlement in such a remote and extreme environment; as such, literature, as well as institutions such as NASA, refer to McMurdo as
providing “an environment on Earth that most closely parallels the conditions of isolation and stress to be faced on long-duration human missions in space” (Mars, 2018). This thesis seeks to examine salient challenges of remote and extreme settlements primarily to prepare for these ever-more-extreme settlements and subsequent urban planning challenges.

To examine pitfalls of remote, extreme settlements, this thesis sought to uncover sources of disconnect between rigorous master planning and the resulting poor quality of McMurdo’s built environment. The extreme location of McMurdo Station provides the ancillary benefit of mitigating influencing factors between planning and implementation. The direct relationship between the two cannot be conflated with a real estate market, for example, as many typical factors influencing urbanism simply do not exist in Antarctica. In order to discern and substantiate specific planning failures, the thesis introduced a unique methodology to determine what quantifiable elements of McMurdo Station point to policy success or failure related to master planning. A Building Information Model (BIM) is not typically used for urban planning research, although the scale of McMurdo Station offered an opportunity to employ BIM analytical tools outside the suite of tools standard to the planning profession. Applying BIM tools provided the ability to empirically ground the conceptual questions of station functionality to determine what planning policies failed specifically, to what degree. Perhaps most critically, the BIM was used to provide another degree of cross-validation beyond the standard practices of examining literature and conducting interviews: if the station was not substantially improvable, this counterfactual would be substantiated specifically and quantitatively through this non-standard approach. Additionally, the use of a BIM to analyze planning outcomes may help establish these tools as cross-disciplinary, exposing architecture and engineering practices to
planning concepts while providing a method for empirical evidence and cross-validation for planning research.

Fortunately, McMurdo Station is well documented and extensively studied, providing the groundwork for a comprehensive analysis of the planning and production of the station’s built environment. Specifically, the planning and development of buildings at McMurdo are central to this thesis because of the richness of available data on the existing buildings and the general consensus is that McMurdo is a “collection of buildings” constructed with no clear master plan (Davis, 2017). This consensus is a direct audit of the master planning process: five master plans were produced over the history of the station in 1961, 1979, 1995, 2003 and 2015, although the existing built environment maintains many low-performing, prefabricated structures intended for temporary use. Many of the buildings are inefficiently arranged and operated, and some are poorly maintained (Blue Ribbon Panel, 2012). Despite these planning efforts, an ‘ad hoc’ development of the station was standard practice. According to the Blue Ribbon Panel (2012):

The site, essentially a small town, was constructed with no clear master plan but rather in response to the tasks at hand and the availability of funds over the years. This somewhat haphazard arrangement inevitably leads to wasted resources and also raises serious safety concerns. (p. 9)

The apparent failure of master planning to take hold despite five master plans being produced is central to this research. This thesis will introduce relevant literature, followed by a critical analysis of the planning and development of McMurdo Station in Chapter 2. The BIM sections will be discussed in Chapter 3: Analysis of McMurdo’s Master Planning and Resulting Built Environment. Chapter 3 is divided into separate sections based on each distinct portion of the BIM methodology in order to immediately discuss findings where relevant. Principal conclusions from each finding section are discussed in Chapter 4: Conclusions.
Literature Review

Weighing theories of urban planning from ten-thousand feet against the master planning and outcomes of McMurdo Station immediately warrant an investigation into the disconnect between thoughtful, iterative master planning and the outcomes of that planning. The broad spectrum of perceptions and ideologies surrounding the role of urban planners is reviewed here through its major evolutions since the postwar, a roughly equivalent timeline of McMurdo’s planning, and with respect to the research questions regarding planning aims and effectiveness.

The broadness of planning ideologies is a result of the complexity of urban planning and planning theory. For example, facets of urban planning exist within larger debates about the roles of the state, markets, or society. Theories of planning have not surprisingly brought together sources and fundamentals from related topics such as social science, economics, and architecture, the composite of which is often frustratingly complex, interwoven with tangential theories, or seemingly unlimited in scope (Fainstein, 2015). Aspects of the planning process and decision-making power are distributed among various departments, institutions, administrators. The result of this practice cannot be tied exclusively to any one of these actors, and more importantly, many of the participants in planning are not planners themselves. The agency of decision making lies with constituents, elected officials, civic leaders or industries of various sort, most of which do not maintain a background in urban planning.

Further, planning theory has many subdivisions including the “dueling camps” of methods-based theory and object-based theory. Methods-based planning theory focuses on the process of decision making in the realm of spatial development, while object-based theory is focused on the spatial development and regulation of society and the built environment. In the
context of McMurdo Station, a methodological theorist would perhaps contemplate the long
history of sporadic planning efforts of the station, the repeated master planning efforts and
subsequent failures of that planning. The processes of investigating problems, determining
solutions, planning to rectify and resolve these issues, and finally funding the plans’
recommendations are integral to the decision making behind the evolution of the station. The
station remains today subject to continuous methodological planning processes; however, these
processes have historically failed to produce more than a slow and incomplete adoption of their
best practices and recommendations. The object-based planning approach would likely focus on
the task at hand: how to improve McMurdo’s flagging infrastructure, especially buildings, and
the logistics and operations of the stations. One might analyze the components of the station,
taking stock of the productive capital, the maintenance schedule, the distribution of warehousing
and how to consolidate it appropriately and efficiently. These two planning camps naturally lead
to different priorities and research approaches; the difference between these two approaches
underpins the two-part approach to the research presented herein.

The goal of urban planning has been hotly debated, though the Rawlsian perspective of
creating the ‘just’ city is central to some leading scholars; as such, urban planners generally work
with the objective of improving the city and the quality of life of its inhabitants (Fainstein, 2016).
The conventional historical perspective of modern urban planning is, according to Fainstein
(2015), based on several separate movements that arose from the twentieth century: the
pioneering age from the late 1800s to World War I; the period of institutionalization and
professionalization from 1920 to 1945; the postwar era of standardization, crisis, and
diversification of planning from 1945 to 1975; and the current understanding of the planner as
the strategist, mediator, and advocate. This narrative has taken the form of disciplinary mythology, with a notable exaltation for powerful men reconfiguring vast urban areas. According to Sehested (2011), planners’ perceptions of themselves are largely reflective of the dominant discourses in planning, communicative and participatory planning in particular. Past technocratic and managerial planning perceptions are giving way to more democratic approaches. For example, Patsy Healey (1992) argues for navigating the trade-offs of urban planning through dialogue to create a mutual understanding of constituent groups. This communicative approach seeks a collectivist outcome where planning priorities are developed through a shift from the subject-object conception of reason to reasoning formed within “inter-subjective communication” (p. 150). This approach is argued for as more historically situated and practical approach to overcoming differences between individuals in communities while seeking progress.

The communicative approach is interestingly supported through a different perspective: in The Science of “Muddling Through,” Lindblom (1959) refutes the popularly described “comprehensive rational method” of planning, where an administrator is tasked with describing all possible policies and policy outcomes, explore endless and perfect information to find the conclusion. The reality of constraints that prevent an exhaustive review of potential policies and outcomes is the “muddling through” that is practiced by actual administrators who have multiple responsibilities and cannot produce exhaustive studies to find the exactly balanced policy. Literature often outlines the exhaustive approach as the best practice, despite muddling through as the actual practice. For instance, in Darwin G. Stuart’s Rational Urban Planning: Problems and Prospects (1969), six basic steps are outlined: identify goals; identify inputs such as
programs and policies; develop models for prediction and evaluation as well as alternative approaches; weigh model against contextual economic and social activities; determine relative importance of each goal; select highest-scoring policy based on previous steps (p. 152). Stuart identifies similar shortcomings of this approach, namely the costly nature of the rigorous comprehensive rational approach, and offers a program-policy trade-off model, similar to the approach described by Lindblom, as more realistic within the confines of resource and time constraints faced by administrators and planners (p. 180). According to Lindblom, successive limited comparisons of policies point to the idea that agreement on policy, in much the same way as agreement on an objective, is the best and ultimately the only way to determine which policy is “best.” Agreement on a policy indicates the policy is best in that disparate views of objectives and values align to support it. The rational comprehensive approach of attempting to compile all important information, itemize and measure all potential repercussions, and convince various administrators of the superiority of policy despite conflicting values and objectives is an impossibility itself (Lindblom, 1959).

*Urban Planning Theory Since 1945* offers a historical context that is applicable to the scale of the subjects of this thesis. Taylor (1988) focuses on town planning and primarily contests “miserable” urban environments that many people are “condemned to” do not have to be such. Specifically, Taylor argues the central questions of town planning theory are 1) what is a quality built environment composed of, 2) what conditions allow these to be realized, and 3) how can town planning accomplish this goal? Modern town planning theory suggests that town planning is a social practice that requires sound judgment on how to improve a place that otherwise would not be improved without planning. Additionally, defining what is best for a
community in terms of the built environment can be done through rigorous analysis: through a community’s views of environmental quality; what sort of attributes make up a quality environment; observing tensions that can arise from distinct components; what desirable qualities have been created in the past and how to reach those qualities in the present and future. This theory of town planning relies heavily on a communicative approach: the views and contentions of a town’s inhabitants on a variety of topics such as economics and aesthetics are central, as planning relies on these views to intervene and improve the environment.

From this survey of planning literature, urban planning evidently refers to the process and outcomes of allocating resources related to and inclusive of the built environment. This process can be concerned with the quality of the built environment and the quality of life of residents with a desire to improve both. Working backward from the consensus of McMurdo’s vastly improvable built environment (quality of life, efficient allocation of space, operational efficiency, others), theory suggests a breakdown between the planning and resulting built environment. It is argued here and in subsequent findings and conclusion sections that a localized approach to planning is absent for McMurdo Station. Despite extensive community-driven data collection taking place during the master planning process, this takes place on average more than a decade apart and does not constitute ongoing local planning. Critically, planning takes place within “allocative and authoritative systems” (Healey, 1992); these systems are far removed from McMurdo. The administrative, political and budgetary components fundamental for successfully implementing master plans are in Washington, D.C. This separation, combined with an absence of ongoing community dialogue, may have the effect of diluting any urgency surrounding master plan priorities.
For the purposes of this thesis, it is necessary to explore the theoretical and historical underpinnings of extreme settlements. Interestingly, the grandeur of strong men and grand plans present in the conventional historical view of urban planning resonates with the history of Antarctic exploration: McMurdo Station was built on Ross Island, named by Captain James Clark Ross who first sailed to this part of Antarctica in 1841. While there, Ross also named the sound along the west coast of the island after his lieutenant, Archibald McMurdo, then proceeded to name the two volcanic peaks Mount Erebus and Mount Terror after the ships carrying the expedition. This expedition precedes the wave of early Antarctic explorers in what is referred to as the ‘heroic age’ beginning in 1895 and ending after the First World War. During the heroic age, there remained many unexplored lands in parts of the world; explorers traveled to Antarctica seeking adventure, recognition, and scientific discovery (Davis, 2017). Most expeditions exploring Antarctica were focused on scientific inquiry, despite being often reduced to straightforward efforts to reach the geographic and magnetic South Pole. These expeditions also concerned military, commercial, ideological and personal motives, but carried significant scientific baggage across the continent in order expand the disciplines of biology, geography, geology, glaciology, meteorology, oceanography, paleontology, and terrestrial magnetism (Larson, 2011). Smaller expeditions were led on the continent between 1914 and 1940, but it was not until after WWII that activity on the continent accelerated. According to Collis (2004), the time period after WWII was geopolitically contentious: during this Cold War era, the United States and the U.S.S.R. invested millions to explore and colonize the continent in the name of
scientific discovery, in much the same way space exploration was conducted with a backdrop of escalating tension between superpowers.

The Antarctic Treaty took effect in 1961 and provided a framework for international cooperation with an emphasis for keeping Antarctica a peaceful land for scientific inquiry (Haward, 2011). The claims on Antarctica were not struck down by this treaty and exist today, but are not formally recognized or enforced. The Antarctic Treaty was written to engender peaceful science and cooperation between nations and preserve the environment. To the extent practicable, workers often exchange between stations operated by different nations. For example, McMurdo and Scott Base (operated by New Zealand) are adjacent and share power from several wind turbines. McMurdo Station, originally a military endeavor, then handed over to the National Science Foundation, stands in a larger context of imperialism, colonization, and conflict despite this commitment to peaceful science. As such, the historical spectrum of territoriality and frontier settlements should be explored to situate McMurdo as a national endeavor with international political implications.

The Frontier Thesis, or Turner Thesis, was written by Frederick Jackson Turner and delivered in a paper to the American Historical Association in July 1893. In this paper, *The Significance of the Frontier in American History*, Turner argues the central role the frontier played in the forming of American society: the colonization of the “Great West” was a historical movement that played a significant role defining the character of American institutions, constitution, and democracy. The constant expansion westward of the frontier line is described by Turner (1893):

This perennial rebirth, this fluidity of American life, this expansion westward with its new opportunities, its continuous touch with the simplicity of primitive society, furnish
the forces dominating American character. The true point of view in the history of this nation is not the Atlantic coast, it is the great West. (p. 200)

According to Turner, the “civilized European” is reduced to his “primitive nature” in this process, but in so doing he also transforms the wilderness. The product of this process was a uniquely American identity where the continuous “taming” of land by settlers established an alternative to the typical political, social, and economic structure of European society. The standard institutions of churches, landlords and social hierarchies (especially severely unequal land distribution) were absent on the frontier; thus individualistic and egalitarian values were cultivated over the three centuries of westward expansion.

According to Smith (1996), this sense of romantic adventure, rebirth through expansion, and the frontier as an opportunity appear in The New Urban Frontier, wherein the latter part of the twentieth century the frontier was effectively inverted, reconceptualized as eastern cities. The imagery of urban wilderness provoked emotions of danger and impenetrability akin to those of the primeval forest surrounding settlers in seventeenth-century New England. With these notions of dangerous wilderness are the implications that this place must be tamed and conquered by the forces of civilization. In some ways analogous to the bootstrapping frontiersman of the 18th and 19th centuries, the new urban frontier of the 20th century featured urban pioneers and homesteaders as a new form of folk hero. However, Smith also depicts the belittling and dehumanizing attitudes of these new urban frontiersmen toward existing communities. Their aggressive disposition toward the city is predicated on a lack of social inhibition that resonates with early views of Native Americans on the frontier. Working-class inhabitants amounted to integral parts of the urban environment, but not considered socially or culturally substantial. These communities were effectively subjects to be conquered; the hubris associated with the
colonizing nature of early gentrification aligns with historical examples of colonization and conquering.

In another similarity, the forging of the “national spirit” through westward geographical progress resonates with the presentation of gentrification as the new urban renaissance where the problems of the present will be left behind in the forging of a “new world.” This view is admittedly an extreme according to Smith (1996), but the sociopolitical undercurrents of neighborhood change are relevant to this thesis, especially in the context of forging a national identity. McMurdo Station and especially the South Pole Station stand as flagships for the intention of maintaining a robust U.S. presence in Antarctica. The South Pole Station sits at the geographic south pole, occupying the tip of the triangular slices of geographic claims made by other countries. These claims are intentionally not disputed by the Antarctic treaty, but the treaty lays the foundation for peaceful, nonmilitary operations to take place (Haward, 2011). By occupying parts of these claims, the US makes clear that a physical dispute would have to take place to enforce sovereignty. This acts as a deterrent for these claims to be pursued further.

According to this survey of literature as well as interviews, McMurdo appears to be both forged in and evidence of a synthetic national narrative unique to the U.S. and Antarctic history. This narrative is composed of elements of: the frontier, where opportunity and rebirth can be found on the ‘edge’ of civilization; romantic adventure, where the names of previous heroic individuals are embossed upon the geography; international cooperation as a honorable, productive, less overt alternative to war; the fluidity and egalitarian nature of American life, where extreme conditions effectively flatten social structures; and ultimately the exceptional role
of the United States in preserving peace and deterring conflict on the Antarctic continent.

Evidence for this can be found in the U.S. Antarctic Program (2019) self-description:

> The United States Antarctic Program represents our Nation in Antarctica. Carrying forward U.S. goals supporting the Antarctic Treaty, the program strives to encourage international cooperation, maintain an active and influential presence in the region, and continue to conduct high-quality science research, all while sustaining funding efficiency.

(p. 1)

Additionally, Leidos is the main Antarctic support contract, and the promotional material surrounding personnel recruitment coincides with the narrative posited here, especially with the personal journey and international collaboration elements (Leidos, 2019). This narrative is central to the ongoing justification and investment in science and capital in Antarctica, of which McMurdo Station is a critical component.

**Methodology**

This thesis utilizes a mixed-methods research design, primarily composed of 1) an analysis of the planning of McMurdo Station, including plans, studies, documents and planning techniques, 2) an analysis of the resulting design of McMurdo, and 3) a Building Information Model to analyze the station design to provide evidence for or against claims made in literature and master plans. These three components of the methodology comprise the first three components of the Findings and Discussion section, where each finding is connected to the relevant plan, study, literature, or otherwise, and immediately discussed with the evidence. All three components of this analysis will include or involve in their analysis evidence found in literature, plans, and interviews. Interviews were sought with individuals involved in the analysis of the station in external panel reporting, analysis of the station through study for the purpose of
writing peer-reviewed journal articles, scientific research taking place at the station or dependent field sites, and the master planning process. Individuals involved in the daily operation of the station were not able to be interviewed.

The first section, the analysis of the planning of McMurdo Station, relies primarily on the planning documents, the literature review, and interviews to determine the various planning priorities at different time periods. There are five master plans and two panel reports relevant for this analysis. These plans are listed immediately before the table in the Findings and Discussion section for reference to the table. The planning priorities for each time period are then noted and searched for in the other planning documents, to the extent possible. The 1979 and 1995 master plans could not be located for this thesis, although sufficient descriptions of the planning priorities and strategies exist for some conclusions to be drawn about these plans. For the available documents, the researcher conducted at least one full read of each document searching for planning priorities and strategies, then an additional scan of the documents and a keyword search were conducted to double check for the presence or absence of priorities based on findings in other documents. This cross-referencing of all available documents was conducted to minimize errors in reporting the existence or absence of planning priorities in each. A table was produced to communicate the consistency and inconsistency of certain planning priorities, as well as present the major priorities in a coherent and summarized fashion.

The second section of this analysis, the analysis of the design of McMurdo, relies heavily on the master plans, literature, interviews and a geodatabase made available through the Texas A&M Department of Geography as part of an article by Klein (2008). The planning priorities from the first section are discussed in chronological order with the five master plans. The major
priorities from these plans are discussed in tandem with the resulting improvements or lack of improvements over the period of time between each plan being published and the next plan being published. This chronology is connected with evidence from literature, interviews, and the geodatabase to support the findings. This section does not necessarily discuss the “why” behind planning priorities or failures but outlines what happened over these time periods. Additionally, this analysis is composed of a spatial analysis seeking to measure the relative “density” of the station buildings. This section focuses primarily on the change over time of buildings because of the consistent priority in master plans to consolidate structures, the overwhelming evidence that this planning priority would produce significant efficiencies and resource savings (Blue Ribbon Panel, 2012), and the availability of robust data. The geodatabase from Klein (2008) used to conduct this spatial analysis of the station by selecting buildings at the time each master plan was produced, as well as intervals in between so that a relative time lapse of the station and it’s “density” could be observed at approximately ten-year intervals. The selected measurement was a total building area to perimeter ratio of the buildings. This ratio serves as a measure of building density that can be applied across the history of the station. This is in lieu of a more standard floor area ratio, since 1) an area to perimeter ratio provides a standardized density ratio across the station similar to the function of a floor area ratio, 2) an area-perimeter ratio can also be used as a proxy for a surface-to-volume ratio, which is relevant for energy analysis, and 3) there are no established lots, so the typical floor area ratio would not be applicable here. The findings of this section comment on the relative success of each master plan in chronological order, and the consolidation of buildings over time in intervals of approximately ten years. The spatial analysis component provides evidence from these findings.
The third section of this methodology, the Building Information Model (BIM), is used to empirically test specific master plan priorities for feasibility and provide supporting evidence for the findings. The BIM will test the following planning priorities: the possibility that the ‘ad hoc’ or ‘organic’ development of McMurdo may have produced a satisfactorily efficient layout; the lack of a grid as a detriment to the efficient layout of the station; consolidation as a strategy for reducing the distance of trips across the station; consolidating buildings to improve energy efficiency; the possibility of daylighting as a strategy for reducing energy demand for interior lighting. The BIM was conducted with Rhinoceros (Version 6; Robert McNeel and Associates, 2019) and Grasshopper (Robert McNeel and Associates, 2019); additional software components will be referenced in the following explanations where applicable.

The first BIM analysis section, the possibility that McMurdo may already be satisfactorily efficient as a result of ‘ad hoc’ development, was derived as a testing priority from extensive and recurring criticism in literature and interviews that describe the current layout as inefficient in terms of operational efficiency, requiring excessive travel between buildings, and resulting in station sprawl. To test this, the total square foot requirement outlined in the 2015 station master plan, was configured in 300 different iterations, with plausible station configurations created based on the following parameters: the building dimensions (length width), the average distance between buildings, and the number of floors. The building dimensions were determined by subdividing the total square foot requirement by the number of buildings in each model iteration, as well as the number of floors each building would be composed of. The resulting dimensions were then arranged on a grid, and the average street width was added to the dimensions of the buildings so each building was equally spaced by the
street width. The number of buildings ranges from one to 100, the number of floors ranges from one to five, and the average street width ranges from 20 to 100. Every plausible station iteration maintains the same number of square footage, dispersed across the grid based on the parameterized configurations detailed above. No additional software components were used in this portion of the analysis.

The second BIM analysis section, determining if the lack of a grid is a detriment to the efficient layout of the station, was tested using the same grid outlined in the previous section of this BIM analysis. The literature refers to the original layout of the station as a grid with buildings assembled in close proximity; here the grid is used to further consolidate station buildings along one axis to determine the station footprint reduction. The distance between buildings in the X direction remained the same, while buildings in the Y direction were drawn 50% closer. Reduction in overall footprint is measured based on the total area of the grid, which is composed of a rectangular area composed of the hypothetical building dimensions plus the X and Y distances of the street width. The number of these rectangles is based on the number of building subdivisions. No additional software components were used in this portion of the analysis.

The third BIM analysis section, testing consolidation as a strategy for reducing the distance of trips across the station, was measured by adding up the total existing residential square feet based on the geodatabase published by Klein (2008), and reconfiguring it closer to the center of the station in one to four buildings of variable stories. The difference in the average distance from the existing residential spaces to the central building was compared to the average distance of the reconfigured spaces to the central building using the building centroids. The
distance from residential space to the central building was selected as a trip that likely every resident would take on a daily basis; if a significant reduction in distance could take place, this reduction would render significant cumulative time savings for residents. This analysis did not use additional software components.

The fourth BIM analysis section, consolidating buildings to improve energy efficiency, was identified as a planning priority in the most recent master plan (OZ Architecture, 2015). This priority was tested using EnergyPlus (Department of Energy Building Technologies Office, 2018) in conjunction with Ladybug and Honeybee components (Roudsari, 2019) for Grasshopper to analyze the energy efficiency of a set of plausible building configurations. Each analysis was run on one plausible building configuration that was representative of a set of buildings if the total square foot requirement of the station, 356,988 sq ft, were divided equally among this range of buildings: 1, 2, 3, 5, 10, 15, 25, 50, 75 and 100. The researcher was not able to conduct this analysis with multiple floor heights, so each building configuration is only one floor.

The fifth BIM analysis section, daylighting as a strategy for reducing energy demand for interior lighting, was conducted using the DIVA plugin (Reinhart et al., 2019) for Grasshopper. This priority was identified by the latest master plan (OZ Architecture, 2015). The daylighting analysis was conducted on the same station configurations as the energy analysis. The DIVA component produces a grid on the analysis surface, in this case, the interior space of each building, and estimates the annual daylight autonomy. This metric determines the percentage of time each grid cell can rely on daylight alone for meeting lighting requirements for working conditions. The glazing percentage was set to 11% in keeping with the new master plan. A sun path diagram was also produced to visualize the annual sun path and further substantiate
findings. The findings of all five BIM sections are discussed individually and then summarized in a conclusion section following BIM findings.

After these analyses are conducted, the findings are further expanded upon in additional sections discussing why planning did not take hold, which covers planning practices, social characteristics of the station, and the politics and budgeting of McMurdo. Following these discussion sections is a synthetic conclusion where major findings from secondary case studies are compared to McMurdo, and observations about extreme settlements are posited.
Chapter 2: Planning and Development of McMurdo Station

This chapter first examines the planning history of McMurdo Station and the resulting development, then compares the master plans and discusses findings.

Master Planning Chronology, Priorities, Successes and Failures

1961 Master Plan

McMurdo Station was first built by the U.S. Navy for participation in the International Geophysical Year in (July 1957 to December 1958) and was composed of temporary structures and no utility infrastructure. The first master plan *Preliminary Study for Reconstruction and Improvement of U.S. Naval Air Facility McMurdo, Antarctica* envisioned the station as permanent, efficiently arranged, and highly functional, composed of standard prefabricated structures with interconnected, closed passageways (U.S. Navy, 1961). During the 1960s, the U.S. Navy established permanent infrastructures such as larger buildings with longer lifespans and more insulation, electricity distributed through overhead power lines, utilities and expanded roads (Klein, 2008; Davis, 2017). The following site plans (Figure 3) from the first master plan indicate the size, location and use of existing and planned structures.
Figure 3. McMurdo Station 1961 Existing Conditions (top) and Development Plan (bottom). U.S. Navy (1961).
Evidence from Klein (2008), as well as photos of McMurdo from this time period (Figure 4), support the finding that the first master plan was implemented to a substantial but incomplete degree. Several of the plan priorities were accomplished, such as the building of utilities, expansion of roads, and the replacement of smaller structures with a higher-performing building stock. The station core facility was built in 1969 as part of this master plan and remains today the largest building at the station. In keeping with the priority of consolidation, this core facility building replaced several smaller buildings with its footprint. The station saw the most significant increase in the average area to perimeter ratio of buildings in the time period between 1961 and 1970, although the station footprint expanded significantly as well. However, according to Davis (2017) and Klein (2008), most of the recommendations of the 1961 plan did
not materialize: “With the exception of a substantial housing and dining facility and several warehouses, the development of McMurdo Station did not follow this plan” (Klein, 2008. P. 131). It is not clear why this occurred, but many sources that describe the history of McMurdo’s development tend to follow a similar mantra: McMurdo was developed in an ad hoc fashion; buildings were located and built when and where resources and an available flat area coincided. This pattern is similar across the planning timeline: plans provided details for improving the station, and these recommendations were followed to a limited degree.

**1979 Master Plan**

The 1979 plan occurred after McMurdo began the transition to the NSF from the U.S. Navy. It is noted this transition period lasted until the 1990s and manifested in the prioritization of science over facilities maintenance and investment. As a result, a slow atrophy of McMurdo infrastructure set in and continues today (Davis, 2017; Blue Ribbon Panel, 2012). The 1979 plan reportedly focused on replacing small, temporary buildings with larger more efficient structures in an effort to work toward a vision of the station as a campus-like environment. This planning effort sought to define land use areas based on large structures such as the central facility, and designate those areas for consolidating related functions. This plan also identified the need for zoning to separate incompatible facilities and co-locate similar uses. The plan reportedly recommended allowing the more organic development of roads in lieu of returning to a street grid. This, in turn, reinforced the organic layout of the station (Davis, 2017). Additionally, this plan sought to incorporate utilities and personal privacy into the planning of buildings. After the 1979 master plan was released, the NSF followed plan recommendations and built 11 new
dormitories, a new heavy vehicle maintenance facility, and the Crary Science & Engineering Laboratory was opened in 1991. According to the 2003 plan, significant consolidation of facilities was achieved, as well as improved circulation (DMJM, 2003). While some consolidation of facilities occurred, the claim that these were significant is disputed later by mapping McMurdo facilities over time (Figure 7); significant consolidation based on average area-to-perimeter ratio only took place from 1961-1970, after which increases in density were more marginal. According to Klein (2008), the station development generally followed this plan, although incremental development continued to take place.

1995 Master Plan

According to the 2003 master plan, the period between the 1979 and 1995 master plans involved significant growth of the USAP, with subsequent changing operations requirements. This claim is supported by the 1997 Antarctic External Panel, which states during this time period, a substantial increase in the number of science projects, support personnel, and capital development took place, including science-related buildings and equipment. This growth, in comparison to a relatively steady budget for facilities and maintenance, is attributed to the better utilization of science support infrastructure (NSF, 1997). It was also during this time the administration of the station slowly transitioned from the U.S. Navy to the National Science Foundation; this transition was visible in the types of buildings constructed (more permanent), and evident in the increasingly disproportional bias of funding allocation toward science and away from facilities maintenance (Davis, 2017). The 1995 master plan also reportedly noted a “strong awareness for the need prioritize future construction projects.” It is not clear why this
need arose, if it is connected to the increased number of projects and personnel, or if it is significantly different from the ongoing understanding that the station is substantially improvable. By 2003, four of the 10 priority projects identified in the 1995 plan were completed. These include replacement and renovation of specific facilities, such as remodeling the dining room, replacing bulk fuel tanks, and remodeling three of the largest dormitories. Three major facilities were reportedly constructed that were not identified in the master plan (DMJM, 2003). This admission by the 2003 master plan is significant, offering insight into the impact of the planning process: either the 1995 plan was not thorough enough to define these needs and prioritize them, the station evolves at a pace that identifying future needs is difficult, or a combination of the two.

2003 Master Plan

The 2003 master plan identifies a new area for expanding the logistics and warehousing zone, despite identifying the need to reduce the station footprint. Some consolidation opportunities were identified within this updated zoning plan (Figure 5). This plan focuses on land use, with a heavy emphasis on separating vehicles and pedestrians. Interestingly, the plan notes the layout of the station spurs excessive travel between buildings, introducing another factor of resource inefficiency. Most notably, this plan takes into consideration elements of design impacting human comfort and support, advocating for the replacement of overcrowded workspaces, improved station wayfinding, and strategies for reducing staff turnover. This plan sets a goal of 40% of the population housed in single rooms by 2008, one of the main complaints of station workers. The plan also advocates for better climate control for individual rooms,
“overcladding” older structures for improving insulation, and preservation of historical and cultural aspects of the station, all priorities unique to this master plan. At the time of this master plan release, there were an estimated 90 buildings at McMurdo, supporting nearly four times the number of scientists since the late 1960s, from 260 to approximately 800 in the 2003-2004 season (Klein, 2008). The upgrading of fuel tanks at the station was nearing completion at this time as well, after the project started in 1993. This effort provided larger fuel tanks on a smaller area. This construction took place in conjunction with upgrading piping to prevent leakage. According to Klein (2008), the station footprint grew rapidly in the 1960s, and much slower after 1970. Incremental consolidation such as with the fuel tanks has contributed to slow densification on a relatively equal area over time.
Figure 5. Existing (top) and proposed (bottom) zoning plan. DMJM, 2003.

2015 Master Plan (Master Plan 2.1)

This master plan is the most ambitious in terms of the consolidation, upgrades and total investment taking place. This plan is also similar in scope to the 2003 and 1961 master plan, offering prescriptions for improvements to every support system. It is similar in approach to the 1961 master plan as most buildings are planned for replacement: the station is planned to be consolidated into approximately 20 buildings from an estimated 100 (Figure 6). This plan and the 1961 plan both involve a level of completeness that is apparent in the planning of covered passageways and a complete site plan. On the other hand, the 1979, 1995 and 2003 master plans recommended an incremental approach in keeping with the administrative and budgetary constraints. According to a recent press release, the 2015 master plan has passed the Final Design Phase, the last of three design phases outlined by the USAP. The following steps are Construction and Ongoing capital investment and support (Future USAP, 2019).
Figure 6. Existing station layout (left), planned station layout (right), and view from north of planned station layout (bottom) from Master Plan 2.1.

According to interviews, this approach was deemed possible due to the occurrence of a “perfect storm” of urgency, leadership, and funding. It is possible that urgency developed in part over the last two decades from increased scrutiny, namely the external panels and other reports. The Blue Ribbon Panel was recommended by a letter from the Office of Science and Technology Policy in July 2010. In this letter, the importance of the USAP to international diplomacy, scientific endeavors, climate change, the changing nature and requirements of science were all cited as reasons for investigating the USAP operations. The letter requested the formation of a panel led by the National Research Council (NRC) to identify the changes to science conducted in Antarctica and the Southern Ocean, and the Blue Ribbon Panel (BRP) to make recommendations of future operations based on the NRC report. The NRC report focused on changing science and support requirements in the next 20 years and was not critical to this thesis, while the BRP focused on outlining the infrastructure requirements and investments needed to deliver the science support (BRP, 2012). Master Plan 2.1 will, similar to other master plans, be implemented over a 10-year period. This master plan is the only plan with a distinct budget program for funding.

_McMurdo incrementally, disjointedly built larger buildings and increased area to perimeter ratio but did not achieve a reduced footprint._

This section details the goals and the results of master planning over the lifetime of the station. The first master plan, _Preliminary Study for Reconstruction and Improvement of U.S. Naval Air Facility McMurdo, Antarctica_, identifies 68 individual structures in the existing conditions site plan. This number conflicts with the observation by Neider (1974) and Klein
Hudgins 37

(2008) that by 1960, there were 90 recognizable structures at McMurdo. Klein utilized aerial photography from the U.S. Geological Survey and available station documents to identify structures and produce the geodatabase for examining the station development over time. These photographs of the station were “plentiful” beginning in February 1956 (Klein, 2008). It is unclear why the first master plan would conflict with these sources, although the plan explains the process of its own production, and may have included incomplete information:

A conference was held in BuDocks on 25 January 1961 for the purpose of gathering all pertinent planning data possible and to request that the immediate and long term requirements for NAF, McMurdo be furnished BuDocks so that an orderly plan for development of the facility could be prepared… The conferees were apprised of the urgent need for firm requirements and informed that if they were not furnished within two weeks, the Bureau would develop the requirements from available sources and proceed accordingly. At the time of this report, none of the requested data has been received. (U.S. Navy, 1961, p. 2)

It is unclear exactly what information is missing from this document, and if that includes any portion of the station at that time. The geodatabase is used for this thesis to examine the relative density of station buildings; despite the conflicting information provided by the first master plan, the geodatabase is the best spatial data available for examining the station configuration and measuring the area to perimeter ratio of structures.

The amount of area required for logistics and science activities to take place is linked to the amount of science being supported, which has been subject to change over the decades. The amount of building space required for the station to operate is also in small part connected to the efficiency of the station. For example, there are currently approximately 20 warehouses at McMurdo that serve as storage for food and material. These are of differing sizes and maintain
different temperatures for their contents. This design is vastly inefficient and adds significant staff hours to achieve each task. Some contents have to be moved several times before they make it to their final destination. This additional time requires more staff to complete tasks, adding to the demand for food, lodging, etc. (BRP, 2012). The latest master plan acknowledges efficiency gains, calling for smaller square footage devoted to each category of a task (OZ Architecture, 2015). This is one of several examples of McMurdo’s low-density sprawling nature producing inefficient operations despite master plans calling for consolidation. Figure 7 uses an available geodatabase of McMurdo’s infrastructure produced by Texas A&M’s Dept. of Geography (Klein, 2008) to create an area to perimeter ratio for the station’s buildings over time to illustrate this finding.
Figure 7. Area to Perimeter Ratios of McMurdo Station Buildings.

These maps show the change over time of buildings and their area to perimeter ratio across the planning timeline at intervals of master plan publishing, or similar interval for coherence. According to these data, the average area to perimeter ratio has slowly increased over the history of the station, nearly doubling from the 1961 average of 8.21 to 15.43 in 2008. In 1961, McMurdo was more of an encampment than a settlement; the area to perimeter ratio was significantly lower at this time. The footprint of the station is also generally consistent across the planning period, with substantial growth in the earliest years giving way to more nuanced station reconfiguration.

**Analysis of Planning and Development of McMurdo**

*Master planning and panel reports produced plans with consistent priorities to rectify observed, detrimental issues.*

McMurdo Station is the object of five master plans over the course of its history, in addition to two reports led by panels observing critical opportunities for improving the station. These master plans and reports collectively call for many similar and dissimilar improvements to the station, ranging from specific building construction techniques to zoning for guiding development. Several themes are consistent across all or most of the plans and reports, identifying planning priorities such as building consolidation. The reasoning behind these priorities often differs with the time period and agency/branch responsible for the planning and administration of the station. Table 1 is provided to help ground the reader in the priorities and context of the station over the planning history. This is not an exhaustive list of priorities for each master plan but provides major themes common or unique to each plan. Not listed here and
perhaps most consistent throughout the plans and reports is the understanding that McMurdo is substantially improvable, suffering from a set of numerous and interconnected issues that are responsive to one another. The master plan contents were analyzed and major findings are communicated here. In the table, they are subsequently referred to as A-E and their date for brevity, and the two independent panel investigations are included as P1 and P2.


<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Consolidation of station buildings</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Improve facilities for operational efficiency</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Replace inefficient or dysfunctional facilities</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Separate incompatible facilities or activities</td>
<td>x</td>
<td>x</td>
<td>N/A</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Reduce station footprint</td>
<td>N/A</td>
<td>x</td>
<td>x</td>
<td>(operations footprint)</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incremental construction to facilitate continued operations</td>
<td>x</td>
<td>N/A</td>
<td>N/A</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Zoning to guide development</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Co-location of similar</td>
<td>x</td>
<td>x</td>
<td>N/A</td>
<td>x</td>
<td>(field sites)</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
Some of the priorities listed in Table 1 are intentionally nonspecific. Take for example the priority “Improve quality and performance of facilities for operational efficiency.” The plans and reports explicitly identify this major theme, then outline dozens of avenues for achieving this goal. The reasoning for each goal is often unique and changes over time with the development of the station and the planning taking place. For example, the first master plan provided a detailed site plan for the construction of permanent buildings in place of the existing temporary structures. In 1961, McMurdo maintained no water, electric, or waste facilities; it was truly a “primitive” encampment (US Navy, 1961). Improved facilities at this time involved building the infrastructure and support systems for a permanent presence. This, in turn, improved operational

<table>
<thead>
<tr>
<th>functions for efficiency</th>
<th></th>
<th></th>
<th>and support)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reuse/renovate existing buildings when appropriate</td>
<td>x</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fire safety standards compliance or fire prevention upgrades</td>
<td>x</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Continue USAP activities for international political purposes</td>
<td>x</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Provide single occupancy rooms for residents (officers)</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Lack of capital budget causing failure to upgrade and maintain station facilities</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Eliminate single-point failure modes, strategic redundancy</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Improve energy efficiency of facilities</td>
<td>N/A</td>
<td>N/A</td>
<td>x</td>
</tr>
<tr>
<td>Renewable energy sources</td>
<td>N/A</td>
<td>N/A</td>
<td>x</td>
</tr>
</tbody>
</table>
efficiency by providing scaled life support systems; it was not operationally efficient to have each individual melt their own snow for drinking water, for example. On the other end of the timeline, the latest master plan calls for design simplicity for ease of operations and maintenance (OZ Architecture, 2015). These two specific improvements demonstrate the consistent planning priority (operational efficiency) at different development stages of the station.

The panel reports do not claim to serve as planning documents but did offer non-planning perspective on dysfunctional aspects of the station or its funding that are relevant to the station planning priorities. Additionally, while some planning techniques differed, plans and reports generally observed and produced plans to rectify many of the same issues over the course of the planning timeline. The three themes consistent across all master plans and reports were consolidation, improving operational efficiency, and replacing inefficient or dysfunctional facilities. Many specific priorities were also consistent across the planning timeline. For example, all available master plans (not including the 1979 and 1995 plans) and panel reports identify the age or lack of insulation of certain buildings as problematic. This was identified as a subcategory to the priority of reusing existing buildings where appropriate. Additionally, the development of substantial IT infrastructure was consistent across plans where this was relevant, notably the 2003 and 2015 master plans and the Blue Ribbon Panel Report (2012). There was a consistent and serious focus on planning for fire prevention, with some plans and reports delving into more specific detail than others. A frequent recommendation with fire safety is the use of non-combustible materials, the subdivision of buildings or the planning of separate structures to reduce the risk of fire spread.
The 2003 and 2015 master plan, as well as the 2012 BRP report, identify the need for improving the appearance of the station to represent the professionalism and serious nature of the USAP and the United States. The goal of replacing temporary buildings is a recurring theme in all available plans, owing to the fact that many buildings intended to be temporary, and subsequently planned for removal are still present today. According to the NSF, the new master plan will finally remove some of the original Geophysical Year structures still in use (NSF, 2019). As is discussed later, it is remarkable how consistent the station has remained despite these planning efforts.

Many priorities are not consistent across plans and reports.

The BIM analysis (discussed in detail later) focuses in large part on the configuration of station buildings because consolidation has been noted as one of the most beneficial outcomes of station redevelopment. Consolidation leads to increased energy efficiency, operational efficiency, reduced station sprawl, and improved safety and wellbeing for inhabitants in many cases (BRP, 2012; OZ Architecture, 2015). At the same time, this outcome has seen limited success over the planning timeline. Other major priorities are less consistent over the history of the station. For example, the first master plan identifies the need to maximize the use of a single type of prefabricated modular structure for the purpose of efficient procurement, construction, adaptability, and maintenance of the station. This standard structure was employed to add simplicity to station operations and maintenance through the standardization of building components. For example, it was to be composed of interchangeable framing members, roof panels and wall panels for easy adjustment over its lifetime (U.S. Navy, 1961). The priority of
“standardization” for building components is a common theme across the master plans and panel reports, although calling for a single standard, prefabricated building for all structures was unique to the first master plan. The most recent master plan advocates for the standardization of building parts for reducing operation and maintenance costs, which is similar in concept but quite different in scale to the priority of prefabricated structures. Interestingly, a high volume-to-skin ratio was identified as a priority in only the most recent master plan. This priority works in tandem with improving energy efficiency and was not noted in other plans or reports. The recommendation for a central facility was unique to the first and last master plan. It is possible the existence of the central services building (Building 155) from 1969 to the present did not spur the inclusion of a central building recommendation for other plans and reports.

Another priority unique among plans was “walkability” to reduce reliance on vehicles, present in the most recent master plan (OZ Architecture, 2015). While the 2003 plan identifies the need to separate vehicles and pedestrians to improve circulation and safety, this was the first use of the term walkability, and first use as a strategy to save on fuel costs. Because the real cost of a gallon of gas in Antarctica is several times the cost in the United States or even the listed cost at McMurdo, improving the ability of individuals to comfortably walk to most station areas would work toward reducing fuel consumption (BRP, 2012). The first master plan outlines the use of covered passageways to provide walkability as a year-round possibility, although does not specifically use the term “walkability.” While the second (1979) and third (1995) plans could not be located and thus could not be examined for many of the planning priorities, existing descriptions of the plans do not include covered passageways or a site plan necessary for
delineating passageways. The recommendation for covered passageways is therefore only known to exist in the 1961 and 2015 master plans.

The 2003 and 2015 master plan identified the need for expanding social and recreational spaces and opportunities across the station. Based on interviews and these documents, there is high staff turnover in part because there are few opportunities for spontaneous interactions between people and few locations for socializing within the station. In these plans, improving the number and quality of social spaces is advocated for as a potential way to help people discover their niche within the station and increase their likelihood for returning to the station in following seasons. A broad survey of planning priorities was communicated here; it should be noted that major themes were more consistent than specific priorities, although many specific priorities are also consistent.
Chapter 3: Analysis of McMurdo’s Master Planning and Resulting Built Environment

Testing the Priorities of Master Plans and Station Conditions

The purpose of this section is to provide evidence to support or refute several claims by master plans, reports, scholarly sources, and especially the counterfactual possibility that the station, through incremental development, may have achieved its optimal state. The BIM is used to determine the extent to which the station as built deviates from the station as planned. The BIM was developed using Rhinoceros and Grasshopper software, along with several additional components written by independent authors. These are cited individually where appropriate.

McMurdo’s ‘organic’ layout is problematic.

This section tests the hypothesis that the ad hoc development and resulting ‘organic’ layout of the station is problematic. Research has identified this layout as inefficient in terms of operational efficiency, requiring excessive travel between buildings, and resulting in station sprawl. To test this, the total square foot requirements outlined in the new station master plans were used as a baseline of the station, and plausible station configurations (Figure 8) were created based on the following parameters: building dimension (length times width), average distance between buildings, and number of floors. Every plausible station iteration maintains the same number of square footage. These plausible iterations take place on a grid, and are set adjacent to the existing station for reference.

Results show the total area of the station is dependent on these factors to a varied extent. Based on this model, the sprawl of the station is much more dependent on the average distance
between buildings and the number of floors per buildings than the total number of buildings. The total number of buildings is more impactful to the station footprint as the number increases because a minimum distance between buildings is required. The space between buildings has a cumulative effect, and increases with the number of buildings. As the number of buildings decreases in the model, the total sq ft of the station is contained in fewer, larger buildings and the spacing created by the average distance between buildings is lower as a proportion of station area.
Figure 8. Plausible station reconfigurations. Each reconfiguration maintains a total of 356,988 square feet.

Reconfiguration 1
Buildings: 5
Floors: 5
Building Distance: 75 ft

Reconfiguration 2
Buildings: 10
Floors: 2
Building Distance: 100 ft

Reconfiguration 3
Buildings: 10
Floors: 
Building Distance: 30 and 75 ft
While it may not be desirable or entirely plausible, minimizing the footprint of the station is unsurprisingly accomplished by consolidating the station into a single large structure, with the maximum number of floors possible. The plausible station configurations with the lowest total station footprint all had four or five floors, and a low number of buildings. Some configurations managed 10 or 15 buildings only by having the minimum street width of 20 feet and the maximum number of floors, which was set to five. These results show the current station footprint is sprawling in large part due to a low average building height and significant distance between each building. To a lesser extent, the high number of buildings plays a part in the station sprawl. For example, the new station master plan consolidates the station into 20 buildings (not including fuel tanks). The station footprint is considerably reduced because the majority of interior space is confined within three large buildings, but also six lodging buildings that are three stories and quite close together. The Crary Laboratory is also quite dense relative to the average McMurdo building, and is also immediately adjacent to the two largest planned structures. Master Plan 2.1 (OZ Architecture, 2015) shows significant conformance to the findings in this model. It is possible the remaining buildings were not consolidated in similar fashion in order to reduce construction costs, reuse recently built, higher-performing structures, or maintain significant distance between structures with nuisance activities such as wastewater treatment, vehicle maintenance and helicopter operations. The conflicting goals of station design, such as separating conflicting activities, work against the plausibility of a single building comprising all elements of the station.
The lack of a grid is problematic.

According to Davis (2017), the original layout of the station (1957-1960s) was a "military grid roughly aligned along two parallel ‘main streets’" (p. 171). The buildings were assembled in close proximity to allow convenient travel between each, with enough immediate distance to prevent the spread of fire. This grid structure allowed for a predictable, efficient layout, and was slowly abandoned for a more organic development pattern based on the availability of open, flat areas for new buildings. The inconsistent placement of new buildings was reinforced by circulation routes that formed without adherence to a grid pattern. Significant station consolidation was achieved in the above station reconfiguration. This consolidation was achieved by setting buildings equal distances apart, between 20 and 100 ft. As would be achievable on a grid, the distance between buildings in one of the two directions can be heavily reduced while maintaining the accessibility requirements from the front or back of the buildings. This would be possible only if the road network was composed of a rectilinear grid, and is not readily achievable with the ad hoc placement of buildings across the existing site. When the distance between buildings in the BIM was reduced for one of the two directions, the station footprint was reduced significantly. When the BIM was composed of 100 buildings, reducing the ‘street width’ in one direction by 50% resulted in a 38% reduction in the total station area. When the BIM was composed of 15 buildings, the same reduction resulted in a 23% reduction in the station area. As expected, the cumulative effect of street width on station area is much more impactful as the number of buildings increases. The lack of a coherent grid may not have caused the ad hoc placement of buildings, but its absence could have played a role in station sprawl based on the results of this analysis.
Trip distances are significantly reduced through consolidation.

Consolidation to reduce trips and trip distance was identified as a priority. The most common trip was estimated as that from housing to the central services building that contains the galley. For this analysis, the existing distance between the centroids of housing and the central services building was measured, then compared to the centroids of several consolidated housing reconfigurations. The larger reconfigured spaces took the place of several small structures nearer the central services building. A significant reduction in trip distance was realized: on average, approximately half of the distance between the original building centroids and the central services building were eliminated through this consolidation. This is in part due to simply moving the new structures closer, although the densifying effects of consolidation allow for substantially more building area to exist closer to the destination of this specific trip.

Consolidation significantly improves energy efficiency.

In the most recent master plan, it was noted high “volume-to-skin” ratios of buildings will require less heating (OZ Architecture, 2015). Results indicate a total of 23.71% energy savings all else equal when the station is reduced from 100 buildings to one (Table 2 and Figure 9). While conflicting planning priorities exist that make a single structure difficult to achieve, it is also worth noting the majority of those savings are had when the number of buildings is reduced from 100 to 15 (16.14%). The most notable reduction in kWh/m² was the 4.94% increment between 25 and 50 buildings. There is a noticeable difference in the change in energy requirements when the number of buildings is between one and 15 (more marginal) as opposed
to when the number of buildings is between 25 and 100 (more substantial). These findings support the priority of reducing the number of buildings and increasing the volume-to-surface ratio. The number of buildings should ideally be reduced to less than 15 if all buildings are of equal dimensions for the most significant energy savings. 2

Table 2. Energy analysis of building configurations.

<table>
<thead>
<tr>
<th>Number of model buildings dividing total sqft</th>
<th>Total annual source kWh for model building (in thousands)</th>
<th>Total source kWh for 356,988 sqft (in thousands)</th>
<th>kWh increment (in thousands)</th>
<th>Increment %</th>
<th>Total kWh increment (in thousands)</th>
<th>Cumulative kWh per sq m increment</th>
<th>kWh per sq m</th>
<th>Cumulative kWh per sq m increment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55,460.38</td>
<td>55,460.38</td>
<td>1,670.05</td>
<td>3.01</td>
<td>1,670.05</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>28,033.40</td>
<td>56,066.79</td>
<td>606.41</td>
<td>1.00</td>
<td>2,276.46</td>
<td>1.94</td>
<td>3.94</td>
<td>3.94</td>
</tr>
<tr>
<td>3</td>
<td>18,845.65</td>
<td>56,536.96</td>
<td>1,076.58</td>
<td>1.94</td>
<td>3,353.04</td>
<td>7.88</td>
<td>11.82</td>
<td>11.82</td>
</tr>
<tr>
<td>5</td>
<td>11,454.39</td>
<td>57,271.96</td>
<td>1,811.58</td>
<td>3.27</td>
<td>5,164.62</td>
<td>14.16</td>
<td>25.04</td>
<td>25.04</td>
</tr>
<tr>
<td>10</td>
<td>5,862.32</td>
<td>58,623.18</td>
<td>3,162.80</td>
<td>5.70</td>
<td>8,327.42</td>
<td>26.86</td>
<td>45.90</td>
<td>45.90</td>
</tr>
<tr>
<td>15</td>
<td>3,977.08</td>
<td>59,656.19</td>
<td>4,195.80</td>
<td>7.57</td>
<td>13,523.28</td>
<td>44.53</td>
<td>70.43</td>
<td>70.43</td>
</tr>
<tr>
<td>25</td>
<td>2,451.92</td>
<td>61,297.93</td>
<td>5,837.54</td>
<td>10.53</td>
<td>19,361.82</td>
<td>65.06</td>
<td>135.59</td>
<td>135.59</td>
</tr>
<tr>
<td>50</td>
<td>1,286.50</td>
<td>64,325.05</td>
<td>8,864.67</td>
<td>15.98</td>
<td>38,226.49</td>
<td>105.54</td>
<td>241.03</td>
<td>241.03</td>
</tr>
<tr>
<td>75</td>
<td>888.76</td>
<td>66,566.68</td>
<td>11,196.29</td>
<td>20.19</td>
<td>51,423.17</td>
<td>166.01</td>
<td>307.04</td>
<td>307.04</td>
</tr>
<tr>
<td>100</td>
<td>686.11</td>
<td>68,611.34</td>
<td>13,150.96</td>
<td>23.71</td>
<td>64,574.13</td>
<td>229.72</td>
<td>336.76</td>
<td>336.76</td>
</tr>
</tbody>
</table>
Figure 9. The most substantial energy savings appear to be had when the buildings are consolidated from 50 buildings to 25. While a single, one-story building may not realistic for this amount of square footage, these results show the significance of moving in that direction.

Daylighting for reducing energy demand from interior lighting is plausible, but conflicts with other station development goals.

The latest master plan identified the design priority of improving daylighting to reduce interior daylighting requirements. This section provides evidence that this priority is not substantially achievable. A daylighting analysis was conducted on the same station configurations as the energy analysis to determine the plausibility of daylighting for reducing interior lighting needs (Figure 10). The analysis produces a grid on the analysis surface, the interior space of each building, and estimates the annual daylight autonomy. This metric determines the percentage of time each grid cell can rely on daylight alone for meeting lighting
requirements for working conditions (200-300 lux). The glazing percentage was set to 11% in keeping with the new master plan. Unsurprisingly, only the cells on the perimeter had moderate potential for daylight autonomy. These cells are 25 sq ft. As is expected, the possibility of daylighting increases with a higher surface-to-volume ratio. If it were pursued as a design priority, it would directly conflict with the goals of consolidation, as daylight autonomy increases with smaller buildings. Any energy savings from increased daylight autonomy would likely be canceled out by increased energy consumption from heating. Daylight autonomy is most achievable on the north side of buildings according to this analysis. As a design priority, daylighting should be a low priority as it conflicts with station consolidation. The potential for daylight autonomy could be increased by with an increased percentage of glazing. For example, the latest master plan clusters glazing around high-traffic areas or where daylighting is used to create a more desirable interior environment.

Figure 10. Daylight autonomy for three plausible station reconfigurations.

For all iterations, the north side of each building (left in the above diagrams) could maintain daylight autonomy for less than half of the year within 25 feet of windows.
The sun path (Figure 11) is useful for determining where the sun is most abundant as a design consideration. According to this analysis, the sun reaches its zenith directly north of the station, which means during some periods of time in the year, the sun only reaches above the horizon to the north. The 2015 master plan calls for a heavily glazed exterior facing south. It is possible the southward-sloping nature of the site combined with McMurdo Sound to the south were prioritized over an increased daylighting potential. The quality of the views facing south is more beneficial from a psychological perspective than the improved daylighting potential facing north. Additionally, this analysis does not factor in the topography of Ross Island; significant hills to the north of the station may impede the daylighting potential, especially when the sun is at a low point on the horizon.
Figure 11. Annual sun path diagrams.

In these diagrams, McMurdo Station is not visible due to scale. The station sits at the center of each diagram, and maintains about one tenth of a pixel.

Sun path diagram, overhead view from southeast.

Sun path diagram, side view from east.
**Principal BIM Findings**

While there are conflicting station design principles, such as consolidation, separating nuisance activities from other station activities, reducing fire risk via multiple-building strategy, and daylighting to a lesser extent, the BIM supports the notion that the disorganized, ‘organic’ layout of the station is problematic, having unnecessarily produced significant distances between station uses. Straightforward reconfiguration of the station saves significant energy and reduces the distance of travel across the station for common trips. It has also been found that the low number of stories for each building is problematic: consolidation could be significantly improved from increasing the height of each building. It was not mentioned in any interview or document why the station was never built more vertically. It is possible that as a byproduct of the ‘organic’ development pattern or limited budget, smaller, cheaper buildings with fewer stories were incentivized. Additionally, the current number of buildings would not be as problematic if the distance between buildings was minimized, although major energy savings can be achieved when the number of buildings is reduced from 100 to 15. This would be most achievable with the station adhering to a rectilinear grid with some capacity to facilitate orderly and efficient building placement. Generally, the ad hoc development pattern has worked against the possibility of a compact, efficient station layout. The most significant reduction in station footprint is achieved through increasing the number of building stories, reducing the distance between buildings, and to a lesser extent, reducing the number of buildings composing the station.
Chapter 4: Conclusions

The literature, interviews, BIM, and history of planning McMurdo Station generally concede the following: McMurdo is substantially improvable through planning. Why then did the recommendations of substantive planning not take hold to the extent needed? As one interviewee described, “Few people take notice of the state of McMurdo until you go over and visit Scott Base and realize there really is a lot to improve.” Many of the reports have mentioned substantially improvable aspects of the station. The following section discusses findings and conclusions on how the station ultimately arrived at this state.

Principal Observations of Planning Practices

Continuous local planning is entirely absent, although it is unclear why this is the case.

The community planning approach taken by the master planning teams and panels in the last two decades did not appear to arise from or engender community planning at a local level in any continuous capacity. None of the master plans identify an existing capacity for local planning or advocate for the development of local planning practices. The standard planning practice advocated for in these plans is embodied in statements such as: “Conscientiously revisit the Master Plan as necessary, since it is a living document, to confirm it continues to reflect the needs of the Antarctic science community and asset management teams” (OZ Architecture, 2015). This call for the revisitation of the master plan exists in the most recent master plan and is not explicitly called for in the 1961 or 1979 master plans. ‘Revisitation’ is not combined with possible planning techniques such as ongoing meetings, even at a yearly pace, in the master plans that were available for this thesis.
Interestingly, the first panel report (1997) identifies the need to revisit the master plan on an annual basis and calls for a budget specifically for capital investment based on findings. This annual revisitation recommendation is the only example of a recommendation for ongoing planning, except for the Blue Ribbon Panel (2012) where the closest call for what could be construed as local planning practice exists in a recommendation to establish a “systems engineer/cost analysis group to continually seek opportunities for cost reduction and better ways of supporting science needs” (p. 28). Based on the recommendations of this document, this engineer/cost analysis group would include certain functions of local planning, such as examination of facilities, their performance, and possible reconfiguration for improving efficiency/performance. It was also recommended that this cost analysis group be replicated for Arctic operations and that in tandem these groups could report to the Director of the Office of Polar Programs. This is the only concrete recommendation approximating local planning practice that could be derived from the master plans and panel reports. The recommendation to report to the Director of the OPP suggests reports of station facilities planning of this capacity are not already routine, further reinforcing the notion that a continuous community-driven approach to station planning is absent. The lack of reporting of facility needs may have played a part in the failure to produce a budget commensurate with the necessary capital investment. Again, it is not apparent what caused the lack of local planning, but it is possible the following observations, configured as paragraphs for clarity, have played a role.

For one, there are no planning staff at the station. There is a station manager whose responsibilities, according to interviews, are demanding enough to keep this individual focused on maintaining the baseline facilities performance in the near-term. The BRP call for a cost
analysis group is the closest approximation of planning staff called for in any of the available reports or master plans.

Staff and scientists working at the station are exceptionally busy, with long-term needs neither embodied in their work, nor their schedules sufficiently capable of adding these priorities. One scientist explained the typical working period of a scientist is short; they are there to get as much work done as possible in a short time frame. This individual said they usually don’t spend more than 7 hours in their dorm. Many work days involve early mornings starting at 6 am and late nights ending at 2 am depending on the amount of work to be done. While a staff member or administrator was not able to be interviewed, reports indicate their work-life balance is similar. A tight budget with competing elements and an operationally inefficient station configuration likely have individuals spread across a heavy workload. This would leave little time or energy for examining the long-term priorities of the station. Maintenance of station facilities falls under the responsibility of the contractor, as well as program management, science support planning, provision of labor, coordination with other contractors, “managing the world’s longest supply chain” and other responsibilities (Leidos, 2019). As such, the contractor is focused on a baseline of facilities performance. The competing elements of the budget (science vs facilities) have led to short-termism that prioritizes science over facilities. According to the Blue Ribbon Panel (2012):

Under current practice, when NSF and its contractors must choose between repairing a roof or conducting science, science usually prevails. Only when the science is seriously disrupted because the roof begins to collapse will it be replaced; until then, it is likely only to be repaired. (p. 7)
In the long term, this style of facilities upkeep is likely the most expensive. Inadequate investment in facility maintenance and upgrades appear to have caused major dysfunctions that are routinely kept at abeyance. It is possible this is common knowledge throughout the station, and likely dissuades long-term thinking and planning. This is not to lay blame on the contractor; the BRP (2012) describes the “make-do, can-do attitude” permeates the station’s inhabitants, and the prioritization of science over maintenance is not deliberate negligence, rather a strong commitment to the duties of the station informing this decision making.

According to interviews, the standard avenues for local planning such as surveys, interviews, and meetings to define issues and priorities are apparently non-existent unless master planning or panel reporting is taking place. Aptly put by one interviewee, “there is no town hall.” There are exceptions to this rule, such as the designing of the Crary Lab, which was opened in 1991 (NSF, 2019), as well as the master planning and panel reporting. According to interviews and literature, an extensive planning process was conducted for this building. Design revolved around the functional use of the building, especially for the science planned to take place. This is one of the best instances of the station consolidating structures into a higher-performing structure with a higher area-to-perimeter ratio. Extensive planning took place for this building, but this is an exception to the rule. General feedback on the facilities by sourcing information from people that live and work at McMurdo is apparently not routine. Additionally, planning for a single structure does not constitute station-wide or systems-level planning.

The station experiences high staff turnover for many reasons, especially the lack of single-occupancy rooms for inhabitants. According to interviews and DMJM (2003), the short duration an individual stays at the station may impact the level of personal investment that would
be instrumental for active participation in long-term planning, were avenues of planning present. Additionally, the political process of budgeting for station improvements is far removed from the station itself. In order for a contractor to upgrade or build new facilities, the funding for such a project must be outlined in the Office of Polar Programs budget, which is submitted to the National Science Foundation and funded by the United States Congress. Requiring an act of Congress for substantially improving the station may be discouraging to even the most motivated inhabitants of McMurdo. Additionally, it was noted in an interview that the station, due to its lack of constituents, whether individuals or interest groups, remains non-politicized in the face of budget requests. That is to say, the USAP is less likely to be mired in a political battle. This apparently serves as a benefit to the USAP, but offers insight into the nature of the station: often referred to as ‘workers,’ ‘inhabitants,’ or otherwise, it is clear the ‘individuals’ working at the station are not treated or operating as an active citizenry. This lack of ‘citizenship’ of McMurdo may be associated with the lack of urgency with improving the station.

**McMurdo has a history of a more rigid social structure.**

According to one interview, McMurdo was socially divided based on organization and responsibility. After the mid-1990s when the station was fully handed over to the NSF from the U.S. Navy, the central gally space was renovated and individuals of every organization and employment type were able to sit and eat together. This was a groundbreaking event from a social standpoint, as people with different skills and experience were suddenly more capable of learning from one another. Not only was this beneficial for growing the social network of individuals, it actually “pays” to listen and learn from the more experienced. In just the same
way that single-point failure modes can disrupt operations or threaten safety at McMurdo, it is argued here that to a certain extent, single-point failure modes exist in a variety of frequent, dispersed and less-critical occurrences, and that these have likely been reduced by the flattening of the social structure at McMurdo.

“If five scientists unload our crates in the field, and none of us brought a screwdriver, then no science gets done. If I had known in advance who on the station has a screwdriver and could have it ahead of time instead of expecting one to be there, I could have had my samples instead spending another half day waiting on a screwdriver.”

There is a learning curve for preventing simple yet costly mishaps such as these; the angle of this curve was likely reduced with the removal of social barriers.

*The structure of the budgeting process is problematic, with no clear solution.*

It has been established in the literature the transition from the US Navy to the NSF reoriented the budget toward science instead of facilities maintenance and capital investment after 1972. It is argued here the budgeting process and priorities have been problematic in multiple ways. According to the Blue Ribbon Panel (2012):

> At present, problems associated with the U.S. government’s prolonged budgeting cycle (well over a year) are compounded for the Antarctic program by its seasonal nature. Consequently, an item approved in the budget normally will not arrive in Antarctica for at least two years after its need was established. In the case of structures, matters are further complicated by a useful building season that stretches only a few months. (p. 19)

According to interviews, the structure of the budgeting process also produces uncertainty. It is not certain, year to year, whether a budget will be approved as requested or approved with modifications. There are often political hurdles associated with new budget elements. Further, trade-offs exist within the budget; for example, the competing elements of science support and
facilities maintenance create uncertainty for how much will be available for either. There are often recurring political hurdles with congressional approval of budgets, which are dynamic year to year as well.

Furthermore, the Government Accountability Office (2018) describes NSF budgeting procedures as substantially meeting seven out of twelve GOA best practices for project cost estimation and minimally met six of ten GOA best practices for schedule development for projects. As a result, this failure to adhere to all standard best practices may lead to the development of cost and schedule estimates that are not reliable. For example, five of the seven projects in the GOA report listed and funded under the NSF No Cost Overrun Policy experienced cost or schedule increases after construction began, despite allocated contingency within all no-cost-overrun project budgets. Two projects of the seven projects were reduced in scope to compensate for cost overruns, while another three experienced increased costs from scheduling changes.

The Antarctic Infrastructure Modernization for Science (AIMS) is an ongoing USAP project to plan and develop Antarctic infrastructure, heavily focused on the redevelopment of McMurdo. This project will fund the station redevelopment according to OZ Architecture’s 2015 master plan with a four-year allocation totaling $355 million to cover planning and construction. This budget includes an allocated contingency for budget overage, and the NSF has not authorized the project as a not-to-exceed cost project. Two key risks of the AIMS program were identified by the GOA: minor scheduling errors in material procurement could produce major scheduling delays in if these materials are not transported on the annual resupply vessel; and the healthy construction market in the U.S. may deter qualified labor from seeking remote, cold
weather employment (GOA, 2018). The most concerning aspect of the AIMS program is the failure to address what is repeatedly noted as central to the atrophying facilities at McMurdo: the lack of a continuous, independent capital budget for developing and maintaining the station (BRP, 2012). While the investment is substantial and takes place over several years, there is no evidence that a similar, long-term decline of facilities and infrastructure will take place in the years after redevelopment.

Conclusions

This thesis posits several conclusions based on the aforementioned findings and discussions. Principally, the development of McMurdo Station was outpaced by its role. From the outset, the non-permanence of the station led to the failure to produce adequate infrastructure and support systems (U.S. Navy, 1961). When the Navy sought to rectify this situation, the conversion of the station to a permanent settlement was incremental and incomplete, with many temporary buildings remaining to this day. Subsequent master plans sought an incremental approach to improving the station, where consolidation and co-location of uses were prioritized (a continuation of the priorities of the 1961 plan). Zoning was employed to attempt to manage this, but the ever-increasing responsibilities of the station could not keep up with the pace of science expansion (USAP External Panel, 1997). As the station aged and the responsibility of station facilities was transferred to the NSF, development and maintenance spending slowed, and maintenance backlogs began to accrue. Maintenance and science ended up competing for the same budget, leading to a self-defeating, repair-when-absolutely-necessary disposition toward facilities maintenance. Nowhere in the budget was there space for extensive reconstruction and
consolidation of facilities; these occurred as needed and when budgets allowed (Davis, 2017). Even so, the station still suffered from inadequate and problematic situations such as single-point failure modes, single-occupancy rooms, and a sprawling station despite nearly six decades of master plans advocating for consolidation of facilities for numerous reasons. It is apparent the political will to accomplish major station objectives did not materialize, and thus the station has been ‘behind the curve’ for the entirety of its lifespan. This situation likely occurred due to the planning techniques: the incremental approach to planning and developing the situation was compartmentalized as an intermittent role of the contractor, and disallowed any local or continuous planning practices from taking place. The incremental nature of development was effectively acknowledged through the adoption of zoning practices in the 1979 and 2003 master plans. The lack of local planning, when combined with a budget composed of competing elements, effectively reduced the priority of facilities planning and resulted in minimal upkeep of buildings and infrastructure.

It is unclear whether or not the implementation of the current master plan will solve the long-term issues facing the station. Based on the interviews and panel reports, the AIMS program is fully capable of achieving its goal: complete modernization of McMurdo station. It remains to be seen, however, if this is a long-term solution to the lack of a capital budget and local planning, arguably leading causes of the planning failures over the station’s lifetime. The AIMS program will fund the redevelopment of the station and claims it will provide “ongoing capital investment and support” in only one sentence on the website (Future USAP, 2019). However, the AIMS description in the FY 2019 budget request, arguably more telling, estimates a total project cost of 354.95 million, ending in 2022. This project is estimated to take 8-10
years. The more specific FY 2019 budget request does not provide details or claim there will be ongoing investment in McMurdo after the project is completed.

Secondary case studies demonstrate the possibility of remote, extreme settlements overcoming planning issues similar to those faced at McMurdo through appropriately-sized and appropriately-allocated budgeting as well as continuous planning practice. For example, Edinburgh of the Seven Seas, described in the introduction, maintains a public works department that approximates the roles of planning. There are several political layers: a governor responsible for overseeing the island; an administrator acting as Head of Government; and Island Council of elected and appointed members; and an Association committee of elected members. This island community has a constitution and legislative capacity, and the compactness of the village suggests an urban boundary is enforced, although a master plan could not be found for this community. This island community appears to have achieved a communicative, ongoing planning process instrumental to overcoming planning challenges evidenced by the urban boundary and successful upkeep of facilities and infrastructure, as well as a successful political structure for communicating needs. Edinburgh holds meetings yearly and newsletters are released every six months (Tristan da Cunha, 2015).

In comparison, the planning history of McMurdo Station appears to have adhered to the comprehensive rational model to a striking degree. This narrow scientific rationalism harkens to urban planning practice prior to 1960, when it existed as “architecture writ large” (Batty, 1976, p. 93). During that time period, planners were compelled to implement plans largely emanating from public health legislation following the garden cities movement and reactions to the negative impacts of the Industrial Revolution. As mentioned in the literature review, this model is subject
to failure due to the exorbitant costs of developing a plan with near-perfect information and convincing stakeholders with conflicting viewpoints of the “right” policies. In practice, McMurdo’s master plans each achieved an implementable vision for the station that attempted to navigate the needs of all stakeholders within resource constraints. A local planning apparatus, with reporting, engagement, data collection, plan flexibility, and prioritization of projects would likely have significantly benefited the implementation of these master plans. The local planning apparatus argued for here does not occur without a dedication of resources. As noted in the panel reports, the budget for improving facilities simply was not substantial or prioritized enough to develop and maintain the station commensurate with the role of the station. The budget necessary to achieve the planning goals would likely have to be inclusive of personnel requirements for local planning to take place.

While some master planning efforts exhibited substantial engagement of stakeholders, notably 2003 and 2015 master plans, this approach was no substitute for an ongoing planning process. According to Healey (1992), a true communicative approach would not be the responsibility of a narrow expert group of architects or engineers, and would take place continuously with stakeholders, not for them. McMurdo’s cascading planning failures can be precisely depicted in terms presented by Healey. She claims that technical and administrative machineries based on scientific rationalism will tend to compromise the development of a democratic attitude and fail to deliver stated goals. Evidence for this abounds. McMurdo Station continues to lack navigable political process or even basic data collection techniques such as occupant surveys. The compartmentalized planning that took place in long increments over the history of the station failed to engage a critical mass of people to see these plans through, or
create vital urgency around these plans. For example, it was recommended in the Blue Ribbon Panel report (2012) that a facilities report should be delivered to the director of the OPP, acknowledging a basic level of reporting to administrators is absent. This, combined with the ‘as needed’ development pattern suggest master planning efforts were not only compartmentalized and incremented but often not followed to a substantial degree (Klein, 2008), effectively ‘shelved’ shortly after their publication.

McMurdo’s planning efforts and the resulting failures of planning could not be more directly related, by nature of the extreme location and environment. As such, the cascading failure of planning and resulting atrophy of infrastructure and facilities is evidence of another principal conclusion of this thesis: extreme settlements are a type of urbanism, the quality of which is determined by the nature of the planning process for the settlement. The communicative approach to planning is all but absent at McMurdo, and the systematic neglect of station maintenance and investment combined with failure to implement planning practices described in the master plans exactly replicate the claims of communicative planning theory.

There is significant value in claiming extreme settlements as a type of urbanism. These settlements and ever-more-extreme settlements described in the introduction are likely to be designed exclusively by teams of architects and engineers, as they will be discerned not as communities or cities but life support systems. As such, they will suffer under the weight of technocratic design and scientific rationalism mandated by the severity of the environment and the grim repercussions of settlement failure. While this is not an inaccurate or irrational depiction, extreme settlements will be subject to systematic failures and atrophy of facilities and infrastructure in the absence of an ongoing, substantial, communicative local planning process.
This is the foremost concern of this thesis: while entirely necessary, the technical and rational components of planning extreme settlements are likely to overcome the communicative planning approaches necessary for their long-term success. For McMurdo, the competing budget elements of science vs. capital investment and facilities maintenance exemplifies the short-termism undercutting any possibility of ongoing communicative planning. While this rational approach achieves the short-term goal of baseline facilities functionality at the building scale, the complete lack of a communicative planning approach has demonstrated systematic failure in the long term for McMurdo. As settlements are attempted over the next century in more extreme environments, the increasing severity of environmental and resource constraints will likely reserve even less priority to communicative planning practices than would be optimal for the scope and roles of these settlements.

Finally, the methodological approach of this thesis is unique, with implications for urban planners. The use of Rhinoceros 6 and Grasshopper specifically allowed for a substantial scaling of parameterized, iterative modeling. The use of the BIM successfully accommodated the purposed of cross-validating the claims of planning documents, interviews, and literature surrounding McMurdo Station. This was achievable due to the richness of available spatial data, not the scale of the station. Parameterizing variables at the scale of New York City is possible with these tools; the only constraints are the capabilities of the researcher, computational capacity, and most importantly, the availability of spatial data. Grasshopper is not widely used in the planning profession, but the availability of plugins useful to this thesis allowed for energy modeling and voluminous reconfiguration of McMurdo, as well as standard GIS analytical methods. As mentioned before, the possibility of cross-validation of claims made in literature
and interviews can be done with a parameterized, iterative model depicting the case study *against plausible versions of itself*, whereas the standard practice would look to other case studies for best practices. It makes possible the removal of significant guesswork and grey area, leading to more substantiated conclusions.

By incorporating the BIM, this methodology fully encompasses both dueling camps of method-based and object-based planning theorists. The BIM iteratively describes the impacts of variations in the built environment, while relying on more standard approaches of interviews and literature to uncover the methodological shortcomings to McMurdo’s planning practice. This more rigorous approach, while more time-consuming and reliant on non-standard skills, should be incorporated into urban planners toolsets because of the ability to produce highly-substantiated results comprising methodological tendencies of both major subsets of planning theory. Additionally, the BIM relied on software and methods standard to architects and similar in scope to engineering concerns (energy analysis, for example). This presents an opportunity for cross-disciplinary coordination, exposing architecture and engineering practices to planning concepts while providing a method for empirical evidence and cross-validation for planning research. While these professions may always maintain fundamental differences in their theory, research, and practice, adopting BIM tools in planning presents the possibility of unpacking the tools, methods, and concepts of each profession and engendering disciplinary collaboration and communication that may lead to improved outcomes for the built environment.
Bibliography


Mostapha Sadeghipour Roudsari (2019). Ladybug Tools: Ladybug (Version 0.0.67) and Honeybee (Version 0.0.64) [Rhinoceros plug-in]. Retrieved March 1, 2019, from https://www.food4rhino.com/app/ladybug-tools


