BEYOND LOCAL AND GLOBAL: UNPACKING THE MISSING MIDDLE IN ENVIRONMENTAL SENSING CYBERINFRASTRUCTURES

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BEYOND LOCAL AND GLOBAL: UNPACKING THE MISSING MIDDLE IN ENVIRONMENTAL SENSING CYBERINFRASTRUCTURES

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For my family and friends

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TABLE OF CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

ICT	Information and Communication Technologies
API	Application Programming Interface
SS	Smart Sensors
PI	Principal Investigator
STS	Science, Technology and Society
CSCW	Computer Supported Co-operative Work
STEM	Science, Technology, Engineering and Management
UoD	University of Dublin(pseudonym)
IoT	Internet of Things
SNS	Social Networking Sites
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
EPA	Environmental Protection Agency
OSHA	Occupational Safety and Health Administration
MPC	Metropolitan Planning Commission
GIS	Geographic Information System

DIY	Do-It-Yourself
GPS	Global Positioning System
GPIO	General Purpose Input-Output
NTP	Network Time Protocol
RTC	Real-Time Clock
UV	Ultraviolet
CWOP	Citizen Weather Observers Program

SUMMARY

Today, when our time's most important issues are framed as either local, global, or some combination of the two, what is the enduring importance of scale? Scholars within environmental humanities and science and technology studies have made calls to move away from local versus global dichotomies. This dissertation explores scale in infrastructures as they occur when resolving tensions between local and global, short- and long-term. Specifically, it addresses the concerns of scalar dichotomies, arguing that infrastructures entail much more than resolving tensions between the aforementioned scalar polarities.

Through this dissertation, I employ ethnographic methods to illuminate the role of scale and scaling in the development of a low-power sea level sensing network on the South-Eastern coast of the United States. My research shows how infrastructures work across scalar dimensions of space, time, and human involvement. On the matter of space, I demonstrate spatial embedding as a scaling strategy where the project scales up by connecting to already existing structures, for example, when sensors are affixed to bridges and piers. Along the temporal dimension, I illustrate how linking the short- to the long-term is a form of scaling. I utilize rhythmanalysis to show how long-term rhythms such as climate change become linked to short-term issues, such as emergency response. I end by unpacking what it means to scale a human infrastructure, highlighting the contextual implications of adding another person or institution. I hope this work provides a framework through which researchers within infrastructure studies and related areas can attend to the missing middle, which contains a plurality of scales.

CHAPTER 1. INTRODUCTION

Loud beeping noises rented the air on a hot and humid afternoon in the summer of 2018. I was seated at my desk, most probably going through some school work. I turned towards the source in my small room, puzzled about where the noise was emanating from. The noise was from the display panel wirelessly connected to the weather station that I had set up outside for my academic study. Fast forward to the Spring of that year, when I obtained funding from my advisor to buy a station to study environmental sensing communities. For the better part of that year, I spent time following citizen weather observers and participating in this community by collecting data. An autoethnography of living with a weather station was how I planned to encounter such sensing communities. Having collected data and lived with the weather station for some time, the noise was unusual. I got up to figure out what the problem was. On the display panel, I pressed the alarm button to turn off the noise.

Upon looking at the device configurations, the date seemed to be off. How could this be? Something seemed out of place at that moment. I turned to the mini-computer attached to the display through a serial connection. The mini-computer in use is the famous Raspberry Pi open-source computer. Here is where I indexed all the data I collected, stored, and accessed through a web interface to explore the data. I pulled out the chart and noticed inconsistencies in the data. All the data seemed to be accurate other than some data that had the wrong timestamp. The timestamp affixed to the erroneous records stated that the collection occurred from the first of January 1980. After some troubleshooting, I discovered that the display through which data transmission occurs

needed backup power. Every time power to the unit would be interrupted, the clock would reset to the first of January in 1980. As someone experienced in working with electronic devices, resets provide opportunities to partially unpack the temporalities of objects. They act as a scale helpful in defining the operational temporalities of the device. This event provided an opportunity to explore temporality, which I discuss later on.

During this troubleshooting exercise, I also noticed that the data transmitted to Weather Underground —a service to aggregate weather data globally— registered some alerts. The alerts pointed to the need for me to recalibrate my station. To recalibrate, I headed to where the station was installed, cleaned out debris in the rain gauge, and ensured that the batteries worked usually. Back in the display terminal, I reset the device to reconnect with the station outside. All new data updates to the platform were correct and accepted. However, data collected spanning a month seemed to be inaccurate therefore discarded or useless to the platform. Here, yet again, the intricacies of scale were revealed. Not only do I rely on a global private infrastructure of weather data to calibrate my station, but my contribution also helps several other scales. Scales span from the regional institutions that use that data for other purposes to the National Weather Service as a body also playing an essential role at the national level among other scales.

The incident above and the tinkering with the weather station during this period helped me interrogate scale and scaling concepts. One interpretive frame is the scale at which sensing occurs. Drawing on Sallie Marston, operating from human geography, she argues that the homestead is a scale constructed for reinforcing capital production and human

reproduction(Marston, 2000). Similarly, in my sensing setup, the homestead scale is where sensing occurs. In the discussion on different scales present, other scales are present. For instance, the global scale refers to the geographical reach of activities spanning the globe. Capital accumulation, for instance, is an example of a process commonly seen as global scale in nature. Back to the sensing example, I am an active participant in collecting sensing data utilized to address long-term questions of climate change and, in the short-term, meet needs such as weather forecasting. Through this lens, my participation is in part global in nature.

Moreover, there is also co-maintenance occurring. On one end, I am part of the socio-technical apparatus that maintains the register by collecting data at my locale, enabling those operating at a larger scale to have higher resolution data. On the other hand, higher scales play a role in sustaining my sensing setup and ensuring my data is accurate and of high quality. This experience of living with a weather station prepared me to explore *scale* and *scaling* at another site. The place that is the focus of this dissertation is a novel smart sea-level sensing cyberinfrastructure developed in the South-Eastern coast of the United States. For purposes of anonymity, I refer to this initiative as the Smart Sensors Project (SSP). Through this project, I explore scale as a concept from the perspective of infrastructure studies. As Paul Edwards put it in his text 'A Vast Machine,' citizen weather observers are part of the infrastructure necessary for climate knowledge production(Edwards, 2010).

The Smart Sensors Project (SSP) as my dissertation's focus presented a great opportunity given the different scales in play. As an environmental sensing cyberinfrastructure, the project brought together academics, multi-scale government institutions, a local non-profit, and different universities across the globe. Moreover, the project entails building an infrastructure for monitoring flooding across the county and resiliency planning related to temporal scale matters. This project is uniquely distinct from the work I had done earlier. The number of people involved and their participation were characteristically different. The areas of focus also spanned different disciplines, and the project was also deploying novel sensing instruments. Unlike the work done by citizen weather observers as part of a globalized infrastructure for producing climate knowledge, project participants frame this project as a hyperlocal infrastructure helpful in making climate knowledge actionable at the local level and producing valuable knowledge in understanding global and regional climate patterns.

Unlike my ethnographic work studying what it entails to be a citizen weather observer, the SSP presented an excellent opportunity to understand how such projects utilize infrastructure in grounding and making climate knowledge actionable at the local level. It is not that weather observation has little to do with climate knowledge production, but rather based on interviews with some weather observers, the collection of data to them seldom had to do with seeing themselves as part of climate knowledge production. Also, this project was concrete and brought different institutions to the table. It also brought different expertise and is entangled with several scalar implications. The movement from a non-existent to existing infrastructure is a scaling translation. This element of scaling is

another reason why I transitioned from the weather observation project to the SSP. In a sense, there were not as many opportunities to study scaling in practice in the weather observation study, unlike the SSP.

For context, I must highlight how I define *scale* and *scaling,* highlighting how I utilize them as conceptual devices. According to the Oxford English Dictionary, scale is the relative size or extent of something(Oxford University Press, 1989). This definition of scale is deployed differently across different disciplines. In geography, it refers to the relative extent of phenomena under study and the hierarchical levels evident when organizing different extents. Within the physical sciences, it is 'contextualized as the extent or scope of the study.' In this form, size, distance, or order of magnitude is considered(Herod, 2011). However, what I think is central to this dissertation is the perspectives of scale from environmental humanities. Particularly here, I rely on Timothy Clark's work which points to the Latin root of the word *scale* as *scala*, which denotes a ladder, step, or stairs(Clark, 2012). For him, a scale usually enables a calibrated and useful extrapolation between dimensions of space or time. It is this idea of extrapolation that I also use to define *scale*.

Within infrastructure studies, several scholars have explored *scale* in the context of reach and scope. In the spatial form, some have dissected *scale* mainly across the small and large-scale axis. Others have dissected it across the short-long term along the temporal dimension. Lastly, and perhaps most common, there has been the exploration of *scale* as constituting a local versus global dichotomy. However, some have employed

the concept within infrastructure studies in quantifying the particulars of an infrastructure. In this specific lens, the relative size or magnitude is in focus. For instance, the idea of scaling up may mean increasing the number of contributors to a project, increasing the number of computing cycles, among other quantifications. For purposes of this dissertation, I explore scale as a way to measure relative size. I employ both duals modes of how we speak about the relative size but also how scopes and extents are defined and demarcated. On the other hand, scaling entails the translation from one scale to another—an extrapolation of sorts as highlighted by scholars within environmental humanities such as Clark and Young. I adopt a position of scale as relational. This position is one several scholars within geography such as Marston and Howitt make(Howitt, 1998).

In my dissertation, I use qualitative methods to study scale and scaling practices as they shape ongoing research on climate change, which is "hyperlocal" in its focus but global in its implications. In other words, research on climate change is almost always undertaken by individuals or small groups in specific locations or institutions and yet almost always oriented towards the monumental task of understanding climate change at a global scale. I specifically rely on infrastructure studies and STS. According to Star and Ruhleder, an infrastructure occurs when tensions are resolved between the local and the global(Star and Ruhleder, 1996). Karasti et al., building on the same argument, write that an infrastructure occurs when tension between the short- long term is resolved(Karasti, Baker and Millerand, 2010). I utilize an infrastructural studies frame to explore scale and scaling practices as both infrastructures and scale are relational(Howitt, 1998; Karasti and

Blomberg, 2018). Analyzing the relation dimension of both infrastructures and scale allows us to understand the relationship between the two. In addition to the relational characteristic, infrastructures display qualities of modularity, scaling and are networked(Edwards, 2017).

As sites where the local and global converge, their relational dimension provides an opportunity to understand *scale*. Furthermore, as *scale* is also relational, juxtaposing the two presents a chance to understand how both influence each other. This positioning enables us to understand infrastructures better and vice-versa. It also helps us contextualize scaling. Therefore, infrastructures are good sites to explore scale and scaling as concepts.

1.1 Contributions

In general, this dissertation introduces the nuances of scale in discussing the local versus global dichotomy, specifically through an infrastructure studies lens. Specifically, this dissertation has three main contributions. The first contribution is that it introduces the nuances of scale to infrastructure studies by unpacking the scalar implications of resolving tensions between the local and the global. The second contribution is a call for denaturalizing the 'local.' Through this position, the dissertation links matters of scalar collapse or the local trap to the framing of the local as the site where activities naturally occur. It highlights the subtleties of how processes and other scalar constructs become materialized at the local and the global. Finally, the third contribution it makes is that it links matters *scale* across different disciplines. Here, it introduces to infrastructure

studies different perspectives from environmental humanities, geography, and STS. I now turn to highlight these three contributions in detail.

1.1.1 Scalar Tensions

Through this dissertation, I introduce the nuances of scale and scaling to infrastructure studies. By nuances, I attend to the notion that scale is relevant in particularizing and provides greater specificity when discussing infrastructures as linking the local to the global. Scale enriches the debate around the local/global dichotomy. Under the lens of scale, I highlight the multiplicities of scale and their social-technical construction. Here, I seek to further the discourse from the local/global dichotomy that has been the primary analytical framework. In taking on the position of infrastructures as resolving tensions between the local and the global, I argue that resolving these tensions entails making something scalable in the sense that scalability involves discarding that which does not translate easily onto other scales. Hence, tensions arise. In this lens, I address how resolving tensions is scaling. More importantly, I argue that infrastructures occur when scalar tensions are resolved and are sites where different scales are aligned. I specifically draw on the concept of *scalar tensions* from geography, especially by scholars such as Shin et al., who demonstrate how actors involved in scalar tensions constantly negotiate the scalar divisions of labor(Shin, Park and Sonn, 2015).

It is crucial, though, to qualify what it means to resolve tensions when we speak about infrastructures. A place perhaps best to begin this discourse is in the work of Star and Ruhleder, who posit that infrastructures occur when ‘tensions between the local and the

global are resolved.' I leave this in the passive form here, given several other scholars within infrastructure studies have picked up this framing and utilized it in the passive form. In this dissertation, though, I have made a conscious effort not to use it in that same passive form. Primarily because of two reasons. One is the demand for ethnographic practice to employ active voice rather than passive. Moreover, not just as a matter of convention but to attend to the agency manifested. Specifically, as some state that 'infrastructures occur when tensions are resolved,' matters of agency seem obscure. Infrastructures do not just 'occur.'

Secondly, is the idea of being resolved seems to present some form of finality or as settled. However, within infrastructure studies, there is a lingering question of when are infrastructures ever complete? Several scholars within infrastructure studies have highlighted the indeterminacy of infrastructures(Edwards *et al.*, 2007; Ribes and Finholt, 2009; Karasti and Blomberg, 2018). Hence, some use the term infrastructuring in attending to that indeterminacy and emergent property(Karasti, 2014).

Also important is the question of who determines when tensions become resolved. Based on Star and Ruhleder's formulation of tensions, they point to the dual paradoxical nature of technologies in transforming organizations. That is, technology is both an "engine and a barrier for change; both customizable and rigid; involves both inside and outside organizational practices." It is a product and also a process. For them, such technological rigidities give rise to adaptations, which in turn require calibration and standardization. They argue that this paradox is integral to large-scale dispersed

technologies(Star, 1990; Brown and Duguid, 1994). They further argue that this paradox arises from "the tension between local, customized, intimate and flexible use on the one hand, and the need for standards and continuity on the other." Tellingly, they position this paradox as emerging from the use of decentralized technologies across vast geographical distances. Through such technologies, the need for common standards and the need for tailormade flexible technologies grow more powerful.

The tension between standards and flexibility is not unexpected. They state that it is impossible to have "universal niches," highlighting that one person's standard is another person's chaos. In a sense, there are no genuine universals in large-scale technological deployments. This position, I argue, is similar to that of Zachary Horton, operating from the environmental humanities, by stating that the perspective of scale within geography takes on a universalized perspective(Horton, 2017). According to Star and Ruhleder, an infrastructure occurs when a larger-scale technology affords local practices. It is important to note here that a larger scale in their work refers to geographic dispersion, that is, spatial scale. Through infrastructures, local variations become transparent as they transform into working relations. Karasti et al. extend this position to argue that infrastructures occur when tensions between the short-term and the long-term become resolved. In both cases, the scholars' empirical ethnographic work settles on the idea of infrastructures as occurring through resolving of tensions. I, however, explore the notion of scalar tensions, demonstrating how participants surface conflicts when working across scales. Additionally, I highlight how participants speak on how scales are aligned and negotiated in order to translate from one scale to another.

By attending to the missing middle, adopting a non-dichotomous frame, and understanding the multiplicities of scale, we are able to contextualize both the local and the global better. In understanding infrastructures as doing more than resolving tensions between the global and the local, we can unpack other scaling forms. For instance, I present spatial embeddedness as a technique deployed in the smart sensing project to scale. I draw on digital and media studies on scalability, primarily focusing on the computer as an abstraction machine(Tsing, 2012). In addition, most literature within infrastructure studies points to standardizing as the mechanism through which the resolving of tensions occurs. Reframing of infrastructures as aligning scales and resolving tensions provides another lens to understand scaling.

1.1.2 Scalar Assemblages

The second contribution is to denaturalize the 'local.' The local's prefacing as the site where all the activity happens leads to scalar collapse(Horton, 2017). By scalar collapse here, I refer to Horton's formulation as an interfacial technique of conjoining two or more different scales within a single medium. This frame enables access from one scale to another by homogenizing the different dynamics and subordinating one scale to another. The tendency to collapse scale occludes difference(Horton, 2017). Other scholars within geography have highlighted the pitfalls of this local focus as the 'local trap'(Purcell and Brown, 2005; Born and Purcell, 2006). How could infrastructure studies also attend to the multiple scales to avoid the local trap, especially in an Anthropocenic context? Lastly, the local is relative as a national sensing network may not be considered local as a city-based

sensing network. Here, I focus on moving towards understanding how infrastructure constructs different scales and is a site where multiple scales are aligned. I introduce the term scalar assemblages to illustrate the scale of infrastructure and the different scales aligned for an infrastructure to work. I specifically use the term assemblage to emphasize emergence, multiplicity, and heterogeneity(Anderson and McFarlane, 2011). It also speaks to a form of indeterminacy. In the context of infrastructures, infrastructures are also indeterminate and are always in the process of making. When are infrastructures complete? Other scholars have studied the temporalities of infrastructure considered to be unbuilt and unfinished(Anand, Gupta and Appel, 2018; Carse and Kneas, 2019).

Though some consider assemblages to be multi-scalar, it is crucial to distinguish the concept introduced beforehand. I specifically foreground the socio-technical construction of scale, showing how those who build infrastructure describe the different scales present and the other forms of scalar constructs built as part of that process. Assemblages are in flux, and in the context of infrastructures, it is essential to understand how newer scales are introduced, translated from one scale to another, or removed. Just as infrastructures are indeterminate and in the process of being, so too are scale assemblages.

Other than contesting the local/global dichotomy, this move is illustrative of other forms of scaling. Understanding how infrastructure defines scales links to how we think about scaling. By denaturalizing the local, we can think through how infrastructure navigates different scales. For instance, how is scaling from the homestead to the national level different? What is the difference between scaling from the global to regional and

shifting from the homestead to neighborhood scale? Through this reframing, I also attend to the reduction that occurs when we talk about the local. The local seems to refer to anything that is not global, almost like a placeholder. The differentiation of the regional from the homestead or other local scales seems non-existent, yet these scales matter in facilitating localization and globalization.

1.1.3 Scale as Multidisciplinary

My third and final contribution is making linkages across different disciplines on scale matters. Human geographers seek to get rid of it, environmental humanities and ecocriticism scholars can't seem to do without it, and other fields have different views on it. Through this dissertation, I hope to weave those different perspectives to produce a coherent use of the term. I highlight how *scale* is discussed within geography, showing how the trajectory has changed in those discussions. Scholars interrogated the term's ontological status, with some arguing for its epistemological state(Marston, 2000; Brenner, 2001; Marston and Smith, 2001). Others further extended the debate by arguing for discarding the concept in its entirety(Marston, Jones and Woodward, 2005). I, however, adopt the term's epistemological status and make a case for keeping the term. I specifically rely on scholars from the environmental humanities who have a history of utilizing the term, especially when discussing environmental governance matters. I specifically rely on Horton, who argues for a pluralistic view of scale within the environmental humanities. He sees the debate within geography as one that adopts a universalized view of scale. I critique this perspective earlier in this introduction. I extend this view to highlight that this universal view leads to a scalar collapse as some assume

that scales are inherently nested. For instance, the assumption that the local is always neatly nestled into the global. Other scholars such as Zylinska argue for a minimal ethics for the Anthropocene by arguing for the need for a minimal scale. For her, this helps prevent scalar collapse and is essential for navigating issues of agency when confronting challenging issues such as climate change(Zylinska, 2014).

The audience for this dissertation is those operating in the fields of environmental humanities and infrastructure studies. This positioning is intentional given the issues of scale as a concept. The field of environmental humanities recognizes the role of scale, perhaps due to environmental governance matters, unlike the social sciences. To me, this is part of the natural/social divide. This dissertation contributes to the field of environmental humanities in a unique form. It explores how *scale* has been explored within that field to introduce the notion of scalar assemblages through an infrastructure. Specifically, it explores how we infrastructures are useful sites through which we could think through the multiplicities of scale. Through this dissertation, I introduce a perspective through which we could draw out and speak on those scalar multiplicities.

Within the environmental humanities, several scholars have explored *scale* in different ways. When discussing the Anthropocene, most see the need to think about the human agency as a scale question. The Anthropocene, by some, is understood as signifying a crisis of scale along temporal, spatial, and causal dimensions. For scholars such as Horton, the Anthropocene and a universal overview of scale leads to scalar collapse. In addition, he mentions that this is due to how we tend to think in mono-scalar patterns. I

draw on this position to put forth the idea of scalar assemblages as a mechanism through which we de-center ourselves when we think of scale and attend to the multi-scalar nature of ecological systems. Additionally, it also helps us think through human and non-human agency.

Other scholars such as Chakrabarty highlight the need to understand human activity across all scales(Chakrabarty, 2012). He specifically argues for the need to "think human agency over multiple and incommensurable scales at once." This position is similar to Timothy Morton's perspective of highlighting the need to understand other non-human scales to think through the Anthropocene and agency issues(Morton, 2013). They do this by stating that all objects emit time and space. Woods takes on a different position arguing that thinking of human activity across all scales is framing the human as scalable. I agree with Woods' position that he puts forth scale variance as a mechanism through which we could think of human agency(Woods, 2014). For him, scale variance means that the observation and operation of systems are subject to different constraints at different scales due to real discontinuities. Through this focus, I argue that scalar differences are centered. However, by putting forth the notion of scalar assemblages, not only do I attend to the variances between scales but instead also attend to how homogenization occurs. That is how things or actions are made scalable. I reframe this issue of the Anthropocene as part of a scalability discussion. In sum, I argue for also attending to scaling practices.

Oran Young, operating from the environmental humanities, makes a case for social scientists to embrace scale(Young, 1994). He argues that scale does not feature prominently in the discourse of the social sciences, yet matters of scale are pertinent in understanding social systems similar to physical and biological systems. In my dissertation, I explore scale with a specific focus on the role scale plays in infrastructures. Infrastructure studies as being part of the social sciences would gain more from contextualizing the nuances of scale. Specifically, perspectives on the multiplicity of scale could help in being more particular in describing phenomena. Within infrastructure studies, a relational view of scale helps in contextualizing both the local and the global. This reframing also provides other perspectives on scaling as occurring not just between the local versus global but rather the translation from one scale to another.

1.2 Smart Sensors Project

My primary field site that is seemingly hyperlocal in focus is the Smart Sensors (SS) project. The project brings together academics, civil society groups, and local governments in a South Eastern state in the United States to address issues of sea-level rise and flooding. For purposes of anonymity, I refer to this state as Ventria. The Ventria coast, especially around the town of Dosta, sits in a low-lying area coupled with a complex hydrological system of swamps and rivers that is further complicated by the phases of the moon, making this site challenging. The project participants position it as a smart city project with sustainability values at its heart. A smart city refers to the use of IoT sensors and various technologies that impresses every aspect of living in a city(Duan, Nasiri and Karamizadeh, 2019). By building this infrastructure, the project acts as a site

where the smart city concept goes beyond the typical data collection framing to one that engages with the notion of resiliency. In a sense, a smart city should also be a resilient city. It is also a way through which the project positions itself as tackling a global problem, the problem of climate change. The project built an infrastructure made up of Do-It-Yourself (DIY) sensors that measure the sea-level rise and water levels in different rivers and swamps across West county. By DIY, I mean that the project did not purchase the sensors "off the shelf" but rather the production of kits by assembling readily available electronic components. I have been embedded in this project since May 2019 as an ethnographer engaging in participant observation and carried out semi-structured interviews. Since then, I have participated in countless online and offline meetings and participated in on-site workshops.

Studying the infrastructural development of the SS project provides an opportunity to dissect scale and scaling. As an infrastructure, it does much more than linking the local to the global. It entails building a network of sensors for flood monitoring, emergency response, and measuring sea-level rise at the local level. Meanwhile, it acts as a site for the production of sea-level rise data and downscaling global climate models at the global level. It is a site where regional models are developed with inputs from the higher resolution data collected through DIY sensors and global climate models. Also, as a scientific enterprise, the project enables knowledge production that is hopefully replicable at other local sites. Tsing also notes the production of knowledge and its application to other sites as a form of universalization or generalization scaled to other sites(Tsing, 2012).

On the temporal scale, flood monitoring and emergency response attend to the short-term needs. On the other hand, the project meets longer-term needs by centering resiliency aims, addressing climate change issues, and attending to matters of sustainability. I argue that the discourse around climate change is also a discourse on reterritorialization in the context of scale. Evidence of this is through the foregrounding of discussions around climate refugees. In sum, as sites that mediate space and time, infrastructures could help us understand scale and scaling, especially as the Anthropocene is also a scale problem.

1.3 Outline

This work engages with material from different fields but authored for an environmental humanities and infrastructure studies audience. The other areas I draw on include literary studies, STS, media studies, and geography. Engagement with the notion of the Anthropocene is also central to this dissertation, given the term's high relation to scale. Different academic disciplines have debated the role of scale as a concept. I highlight some of the perspectives and debates on the term in the literature review. In the first part of the literature review, I explore *scale* as a concept in human geography and the push towards discarding the term. In the ensuing debate, better known as "the scale debates," the term's status either as ontological or epistemological is in focus. The social construction of scale is right at the center of this debate. The other issue around *scale* within human geography is its view as a hierarchical ordering. That is, scales are ordered hierarchically, for instance, the home in the city, city in the country,

the country in the regional, and all as part of the global. I take on the perspective of scale as socially constructed. Infrastructures, such as the SS project, demonstrate this. For instance, as the project scaled to support air-quality monitoring for a segment of the community, a new neighborhood scale was constructed. As members of this community mentioned that air-quality monitoring was more important to them, the project utilized the same infrastructure. They deployed some air-quality sensors specifically for this community. Though the project's initial focus was on emergency response, flooding, and sea-level rise issues, the infrastructure allowed a unique form of scaling—this form entailed supporting another kind of environmental sensing that a local community considered a higher priority.

Though several geographers argue for doing away with *scale*, I reconsider the concept from a standpoint that considers the Anthropocene as a scale problem at heart. I advocate for keeping the term as it allows us to grapple with issues of accretion conceptually. Whether we think of it horizontally as some advocate or vertically, or using a hybrid model which I support, scale relationally allows us to separate one thing from another. This relationality constitutes how we also think about scaling. For example, what constitutes scaling from the city to national scale instead of scaling from the homestead to the global scale?

In the second section of the literature review, I delve into temporality and scale. I draw on literature to highlight time's social construction, drawing from different scholars in STS and CSCW. Here I introduce the abstraction of time and the temporalities related

around clock time, drawing on various scholars such as Giddens and Mumford(Giddens, 1979; Mumford, 2010). I then refer to discourse on "pluritemporalities" and non-clock-based temporalities to indicate how we experience time is not universal(Nowotny, 1992). Discussion on digital time and also how computation has affected our temporal scales are highlighted here. What is most important in this section, though, is the relationship between infrastructures and temporality. I draw on scholarship by Lindley, who argues that time as infrastructure presents a different lens through which to understand temporal scales(Lindley, 2015). I also support my work on Karasti et al.'s claim that infrastructuring entails resolving tensions between the short- and long-term(Karasti, Baker and Millerand, 2010). Engaging with the discourse around temporalities enables me to define the resolving of tensions between the short- and the long-term as temporal scaling. I further extend this position by making the case that clock time mediates scaling as it is abstract, allowing for a translation between different temporal scales. I do note here that, unlike geographical scales, the temporal scale is not as contested.

As mentioned earlier, I draw on the work of Horton on *scale* and the Anthropocene. In this section of the literature review, I spend time on scholarship on the Anthropocene. I draw on the criticism of the Anthropocene on being framed as human-centered and highlight the problems other scholars mention with such framing. Here Haraway's work is central in thinking through different non-human centered perspectives(Haraway, 2015). However, it is mostly scholars from ecocriticism and environmental humanities that speak for scale and its retention. For instance, Clark argued that to understand climate change and other significant issues, the challenge of predicting the causes and

consequences of global climate change requires the interfacing of phenomena occurring at very different scales of space and time. Moving from one scale to another or vice versa implies a calculable shift in resolution(Clark, 2012). With climate change, the scale includes the whole earth, yet on relating the consequences or actions to other scales, the undermining of interventions may occur. Others such as Morton argue that confronting the problems brought about by the Anthropocene entails working across all scales. By introducing the concept of "hyperobjects," he refers to how we may refer to things such as climate change that occur at greater scales inaccessible to man(Morton, 2013). Others such as Chakrabarty, Woods, Zylinska also provide different perspectives on scale and the Anthropocene, which I refer to in this section(Chakrabarty, 2009; Woods, 2014; Zylinska, 2014).

Lastly, in the literature review section, I draw connections between infrastructure studies and scale. Here I draw on the work of infrastructure studies scholars on how scale is conceptually defined. Highlighted here is how scale refers to geographical reach, temporal reach, understood as part of the local/global dichotomy or understand through relative quantifications such as the number of collaborators on a project(Edwards *et al.*, 2007; Karasti, Baker and Millerand, 2010; Ribes and Lee, 2010). This section highlights explicitly how the focus on polarities obscures and fails to attend to the missing middle. By introducing the nuances of *scale* and the multiplicities of *scale*, we can unpack other forms of scaling and other scalar constructs essential for an infrastructure to work.

I then turn to my methodology, highlighting how I utilized multi-sited ethnography and grounded theory to understand the project. I highlight why grounded theory as an approach was suitable given the indeterminate nature of infrastructures. The use of multi-sited ethnography was also essential as it is a valuable method in studying big-science projects that are also multi-scalar. I finalize this section by detailing my data collection methods of participant observation, memos, and interviews. I also detail some of the methodological quagmires of dealing with this project by being reflexive on my role as ethnographer and participant.

After my methodology, I dig deep in the following three chapters to provide evidence for my three central claims. In the first, I explore the embeddedness in the SS infrastructure and how it could act as a mechanism to scale. Here, I introduce the notion of spatial embeddedness to show how scaling as a form of territorialization entails sinking infrastructure onto other infrastructures, structures, or social arrangements. In the following chapter, I define temporal scaling, demonstrating that linking the short to the long-term is a scaling form. Building on Oran Young's position, an environmental humanities scholar, I make the case that temporal scaling is also the application of propositions from one scale to another(Young, 1994). I further provide evidence of how clock-time as an abstraction of temporality enables this form of scaling. In the next chapter, I begin with the question of what scaling a human infrastructure means. I argue that scaling a human infrastructure involves much more than adding another member or institution. Rather, scaling a human infrastructure entails an intentional contextual scaling wherein people or institutions operating at higher scales or with access to other scales are

the ones who enable the project to access the respective scales. I conclude by relating this work to different disciplines, especially infrastructure studies.

Doing this dissertation helped me think through why *scale* is still a relevant conceptual device given our current moment of the Anthropocene that sits in contrast to the elevated emphasis on local, bottom-up solutions. I mainly began my dissertation work by exploring what it means to downscale a climate model. One of my positions that I explored during the initial analysis that I pushed to the side was how downscaling entails more than a mathematical calculation. Framing climate model downscaling as a social-technical process that involves infrastructuring seemed complex to do given that I am operating from a communication and media studies department. Though other scholars have highlighted how downscaling should be reframed as a socio-technical process, to me, going into the intricacies of downscaling as part of infrastructuring seemed challenging. Conveying the mathematical operation in downscaling is not easy. Scholars who do this well without getting deep into downscaling intricacies include Edwards and Krauss(Edwards, 2016; Krauss, 2016). Be as it may, being embedded in the SSP enabled me to unpack and understand how scale is relevant. In the least, scholars within environmental humanities and ecocriticism still believe it is a fundamental concept.

However, those operating from geography who call for discarding the term are also right about how the term is ambiguous and amorphous(Marston, Jones and Woodward, 2005). I agree that the term has become more challenging to convey meaning due to various utilization forms. For instance, I am reminded of the phrase “Research at Scale”

to denote how large-scale research occurs. Similarly, in discussions on technology resources and their ubiquity, it is common to hear the term “at scale.” In a sense, there is a conflation between scale and being large. There seems to be a distinction that seems to fall by the wayside when some equate scale as a social construct with being relatively large or big.

Additionally, I think there is also a conflation between scale and scalability. Scholars such as Hanna and Park, operating from CSCW, make a case for doing away with scalar thinking(Hanna and Park, 2020). As they state,

“‘Scale thinking’ is an approach that centers on and prioritizes scalability. Scalability refers to the ability of a system to expand without having to change itself in substantive ways or rethinking its constitutive elements.”

However, the social construction of scales does not necessarily mean that scalability is the main aim. Especially when doing something familiar in the environmental sciences, such as describing the reach and scope of phenomena, the conflation of scale and scalability does not occur. However, the challenge that I see with the conflation above is that scale is seen only from a growth perspective rather than a descriptive device to think through various phenomena.

Scale is of fundamental importance, mainly due to the paradoxes brought about by various dichotomies. The dichotomies I speak about here, for instance, are local/global,

short- /long-term, small/large, or the micro/macro debates that scholars continue to have in different academic disciplines. To provide an example of how *scale* nuances, both the local and the global, take global climatic change. Global climate change gets localized in different forms. Meanwhile, local changes, in turn, contribute to global climate change. Therefore, linking the local to the global potentially yields better understandings of both scales and their complexities. To concretize this through the SSP, participants highlight and talk of the project as being hyper-local. Hyper-localness alludes to a sense of deficiency in how one may speak of something as being local. In a sense, the data collected from one of the local sensors operated by NOAA (the tide-gauge) was not precise in representing the realities across the county. A higher scalar description of a higher resolution was needed.

At the same time, one of the participants did not see their work as just local. The participant working for the non-profit insisted on their work as not just limited to the city but translated to other places. She pointed to the work on environmental justice they had done with the United Nations and other initiatives with entities in the Global South. Their reach and scope are not limited to the city. I argue that infrastructure plays an essential role as scholars consider them to occur when tensions between the local and global are resolved. That is, they are a concrete way through which the local and the global become linked. Thus, we can understand how linkages come to be at such sites by adopting the multiplicities of scale.

Writing this dissertation during a pandemic also helped me think through *scale*. The World Health Organization, a global institution part of the United Nations, declared the novel coronavirus 2019 (COVID-19) a global pandemic on the eleventh of March 2020. Interestingly within epidemiology, the scale of viral phenomena can be described as an outbreak, a cluster, endemic, an epidemic, or a pandemic, all acting as scalar descriptors. A pandemic refers to an outbreak that is global as the reach and scope are no longer geographically limited. Though COVID-19 is a pandemic, it is localized differently across the world. Before becoming globalized, the virus originated in Wuhan, China. That is, at the time, it was a localized outbreak. In another form of localization, virus variants such as the South African variant, the United Kingdom variant, among other emerging variants, point to how the virus mutated and became localized. In the discourse around scale, variants are named based on their geographical reach and scope, yet these scales are based on political imaginaries. Variants aside, there is also the aspect of interventions taken by different entities in dealing with the pandemic. Schools were closed, access to offices limited to essential workers, and homesteads became sites where work and formal learning happens facilitated by digital infrastructures. The scale of the response in the form of the biggest fiscal stimulus in history to the production and distribution of vaccines is revelatory of the multi-scale effects of a global pandemic.

The assemblage of the different social constructions of scale is evident through this pandemic. Other than the scale demarcations used in describing the relative size of occurrence, other scales are part of this assemblage. How we speak about the relative size of the occurrence is based on the number of infections across the human bio scale. A

localized infection across a significant number of people in the population is an outbreak. If we dig deeper into the human bio scale, other scales are present. Since the start of this pandemic, we have been familiar with visual imagery of how the virus looks. A grey ball-like structure with red spikes protruding provided this image of what the virus is. This image is a representation of what the virus looks like under a microscope. At the cellular scale of the bio scale, the virus embeds itself into a cell to replicate. This replication, in turn, results in a full-blown infection that also enables transmissibility. The virus is excellent at scaling up.

More than the individual and cellular scales, other scales are evident. For those who fall gravely ill, hospitals become another scale for interventions. Doctors work with local health departments and global health institutions to better understand treatment options. It is on the basis of overwhelmed health systems that political administrations representing another scale recommended lockdowns. Some hospitals ran out of ventilators, others out of oxygen, revealing the multi-scalar nature in the production of medical equipment. The issue of mask shortage also highlights how globalized supply chains could result in unreliable health infrastructures. I could go on to describe other scales part of this assemblage such as vaccine production, digital systems for working from home to other issues such as educational systems. Scale is an important concept that nuances both the local and the global. It is because of scale that we can talk of outbreaks and pandemics. I now turn to highlight how different disciplines have interrogated the concept.

CHAPTER 2. LITERATURE REVIEW

In this literature review, I explore scale and scaling across different disciplines. I primarily do this by exploring scale discussions in the dimensions of space and time. I then discuss it from the context of the Anthropocene and infrastructures. This literature review digs into scale conceptually in four main sections.

In the first section, I explore the relationship between scale and space. This discourse mainly emerges from different disciplines of geography. Within geography, scholars commonly refer to the discussions around scale as the 'scale debates.' This section explores the term across its use in physical geography, human geography, and globalization studies. The primary debate around scale was over its ontological versus epistemological status. At the ontological level, the framing of scale takes a form ready to be discovered out there. In the epistemological frame, as a concept, it is a social construct. Here, I support Marston's position and several others thereafter, who argued for its social construction(Jones, 1998; Marston, 2000; Jones, Woodward and Marston, 2007). However, even though more scholars took on the position of scale as epistemological, agency issues and scale as a series of nested vertical structures were considered problematic. The positioning of scalar constructs such as global-continent-country-city as vertically nested scales obscures, in my opinion, and points to hierarchical forms. Marston argued that these are constructs dependent on the viewer and perhaps should be done away with. She also argues that a vertical hierarchical viewpoint engenders atomistic thinking brought about by the micro-macro binarizations(Layder, 2006). Others have championed a hybrid approach that acknowledges scale as both

horizontal and vertical. I support this position that embraces both vertical and horizontal framing(Leitner, 2004). I take this position, especially when contextualizing scale in analyzing the Anthropocene. I will detail later on why I take on this position.

I then discuss scale in the context of time in the following topic. I begin by drawing in the work of Nowotny and Adam on the social construction of time(Nowotny, 1992; Adam, 2002). Adam additionally highlights how western society has conflated clock-time with time and ingrained the perspective of time as linear(Adam, 2002). I support this perspective on the social construction of time. Just as many academics argue for the social construction of space, so too is time. I turn to clock-time, contextualizing the literature within the field of STS and CSCW. I attend to the role of the clock as technology in society across different periods, from structures that pre-dated the clock, such as Egyptian water clocks, to the pendulum and its use in the industrial age. Besides the heterogeneity of time, I build on Nowotny's argument on 'pluritemporalism,' where she highlighted the plurality of time and temporal scales. In this section, I extend the notion of the abstraction of time reified as clock-time as a mechanic that allows for scalability. Similar to the modularity and abstraction that Tsing mentions, clock-time enables scalability(Tsing, 2012). Clock-time enables the translation from one local temporality to another. However, scaling also takes a distinct form where scaling involves translation from one temporal scale to another. I finalize by linking temporality in infrastructure studies to Karasti et al.'s argument that infrastructures occur when tensions between the short- and the long-term are resolved(Karasti, Baker and Millerand,

2010). I argue that clock-time on the temporal scale enables scalability as it provides a standard that brings about the translation from one scale to another.

Issues of the Anthropocene and scale are the next area of focus. I detail the root of the term and address the debates around it. I address the issue of agency as there is contestation in ascribing responsibility. In one form, it is the homogenous collapse of the "we" in describing humans as responsible. In the other form, the term centers on the human, leaving out non-humans. In part, this agency element is what Clark considers a "derangement of scale" where interventions or accountability occurs at the wrong scale(Clark, 2012). Horton makes a similar point though he refers to this condition as "scalar collapse." Scholars within environmental humanities and those who specifically engage with the notion of the Anthropocene acknowledge the importance of scale as a concept(Chakrabarty, 2012; Clark, 2012; Horton, 2017). I also argue against doing away with scale as a concept as it allows us to understand how we got here in the first place and what multi-scalar interventions are needed if we are to tackle significant issues such as climate change. Horton makes the argument for scale by acknowledging the debates in human geography and making the case that the framing from geography views vertical scale as singular and universal(Horton, 2017). He argues that there is no one universal view of scale and makes a case for moving away from a totalizing scalar ladder. I support this position as Marston also states that scale is socially constructed. However, there is the need to acknowledge the different multiplicities of scale similar to how we think of multi-temporalities. Zylinska, also operating from an environmental humanities and literary studies background argues for the need for a universal scale necessary for

minimal ethics for the Anthropocene(Zylinska, 2014). In my assessment, this move for minimal ethics is also evidence of an approach to resolving scalar collapse issues. Uniquely, she argues that scale is not an objective measuring stick but rather part of the phenomenon it seeks to measure. However, what Zylinska and Horton do in their respective writings on scale in my assessment, is that they speak to the multiplicities of scalar hierarchies. Whether as part of understanding a phenomenon or a concept to think with, scale conceptually helps us come to terms with the extent of an object, activity, or phenomenon. In the context of the Anthropocene, this is very important.

I finalize the literature review by looking into scale in the context of infrastructure studies. The common framing of scale is mainly through the 'reach and scope' of infrastructure. However, in the context of scaling up, discussions have centered on simple quantifiable ways. For instance, scaling up is in the context of adding collaborators, more compute resources, or broader geographic reach(Ribes and Lee, 2010). Scaling is also referred to as a translation in the spatial form(small — large scale) or temporal (short — long term)(Karasti, Baker and Millerand, 2010) or local-global(Edwards *et al.*, 2007; Edwards, 2010). However, infrastructures occur when tensions become resolved between the local and the global. Building onto this claim, Karasti et al. argue that infrastructures occur when tensions become resolved between the short- and the long-term. I recast this framing of the local/global short/long term as scales within infrastructure studies. In doing explicitly so, it allows me to reframe the resolving of tensions as a scaling practice. The fact that there are tensions points to unscalability. I argue that resolving tensions entails making something scalable. Within the literature, this is a point that I think is not

made explicitly enough. I further argue that infrastructures and infrastructuring do much more than resolve tensions between the local/global and short/long-term.

To reiterate what this literature review does in terms of contributions to different disciplines. I introduce to geography the discourse on scale perspectives from environmental humanities, literary studies, and Anthropocene studies. Though I support the positions on the social construction of scale, I introduce discourse on the multiplicities of scale and specifically Horton's work against a totalizing vision of scale. The totalizing image presupposes a form of a hierarchy of scales nested into each other like matryoshka dolls. I argue that this totalizing vision is also a zoom issue that assumes smooth scaling. By looking at scale from a perspective of infrastructure studies, not only could we see the different scales at play around an infrastructure but also how infrastructures construct scalar categories. However, and here is where I made a unique distinction, there is an implicit assumption on the nestedness of these scalar categories. The field of environmental governance is an example that challenges the nestedness view.

To restate what I mean when I state that this work contributes nuances of scale in infrastructure studies by marking and highlighting scalar implications as much more than resolving tensions between the local and the global and the short- and long-term. First, I consider the two dichotomies as scalar categories. As academics within infrastructure studies, this is often assumed. By foregrounding them as scalar categories, we able to see how both are linked. Secondly, this also allows us to explore the missing middle in

infrastructuring when we think of other scalar categories or how infrastructures construct scalar categories. Additionally, this helps us think through what scaling looks like through this lens.

2.1 Scale and Space

Scale within geography has generated intense debate and contest. The discussion has mainly focused on questions around the term's ontological or epistemological status. In the ontological form, scale is seen as existing in nature, ready to be discovered out there as Marston put it(Marston, 2000). In the epistemological form, it acts as a device through which knowledge is produced or constitutes a way of knowing. In this section, I dig into scale's use within geography. I begin with its use within physical geography, a branch of geography dealing with natural features and processes. In physical geography, the term takes center stage as it is linked intrinsically to understanding nature. I then explain the use of the concept within human geography, the sub-discipline of geography that deals with humans and their activities. It is here where the idea scholars heavily debate the idea. The final area of interest is the discipline of globalization studies. Here, I demonstrate how the term has been used and contributed to the discourse.

2.1.1 Physical Geography

Physical geography is the discipline that studies natural phenomena spatially. As a discipline for understanding the natural world, scale takes center stage, enabling knowledge production. However, despite operating within the same discipline, the term scale can also be confusing. Three different understandings of scale exist within physical

geography. Cartographic scale refers to the relationship between the distance on the map and the corresponding distance ‘on the ground(Herod, 2011; Jonas, 2012).’ Nothing perhaps highlights the importance of scale to physical geography as maps. A map is a representational device, allowing for the representation of the entire world. However, to fit the world on paper or a computer is not possible. Scale allows for the translation between representational devices and the real world. Scale represented as a ratio helps in doing this translation. The first number in the ratio represents the map’s unit, while the second number corresponds to the distance on the Earth’s surface.

Cartographers distinguish map scales as large or small based on the ratio size. As Jones states:

“A common USGS map at 1:24 000 is said to be relatively large scale, owing to the size of the resulting number, relative to a map with a scale of 1:250 000, which has a much lower value and is, therefore, referred to as smaller in scale. A point of common confusion is that since larger scale maps reduce the Earth’s surface to a lesser extent, they therefore show less surface area, while small scale maps are needed to show large areas. A 1:24 000 map enables viewers to identify urban or rural features such as streams, roadways, and land use patterns, while maps at smaller ratios, such as the commonly used 1:100 000 or 1:250 000 maps, are used to discern the shapes of river basins and state political boundaries(Jones, 2017).”

The distinction between large scales and small scales is crucial as it demonstrates the categorization that physical geographers do when describing phenomena. For physical geography practitioners, a large scale means more details in opposition to small scales where the representation is considered coarse. Later on, I will come back to this distinction to highlight why it matters when we speak about scale.

Another understanding of scale within physical geography is geographic scale. Geographic scale refers to the spatial extent of a phenomenon or study(Lam and Quattrochi, 1992). Though Lam and Quattrochi introduced the term geographic scale, recently, the term 'analysis scale' has been preferred within the field(Montello, 2001). This change was to remove the ambiguity of the term 'geographic scale.' Lam and Quattrocchi also considered this form of scale as observational scale. They provide an example where a study of land use across the United States is considered a large-scale study while a city-bound study is considered a smaller-scale study. The focus on the scale of analysis is telling as physical geography considers the scale of analysis as bound to the phenomenon's scale. As Montello reveals:

"It has long been recognized that in order to observe and study a phenomenon most accurately, the scale of analysis must match the actual scale of the phenomenon. This is true for all three domains of scale--spatial, temporal, and thematic. Identifying the correct scale of phenomena is, thus, a central problem for geographers. Particularly when talking about thematic scale, using data at one scale to make inferences about phenomena at other scales is known as the cross-level fallacy(Montello, 2001)."

As part of this process of determining scale, geographers have to work with the available scale. Montello employs the term ‘available scale’ as, at times, data for a specified phenomenon scale may not be present or available. Geographers thus have to use other tactics such as finding secondary data.

The third understanding of the term scale is phenomenon scale, which denotes the ‘true’ scale of geographic phenomena(Montello, 2001). It is the scale at which geographic structures exist and over which geographic processes operate in the world(Montello, 2001). In geography, scale matters as determining the scale of phenomena is a central research goal. This research goal is due to the view that some phenomena are scale-dependent. For instance, the distribution of dialects is over smaller areas than languages. However, the discipline also recognizes that there are scale-independent phenomena, thus observable across scales. Lam and Quattrochi characterize this scale as an operational scale, referring to this scale as the level at which relevant processes operate(Lam and Quattrochi, 1992).

Though the three perspectives of scale within physical geography are different, the three are highly related. Phenomenon scale describes real-world processes and objects and is related to the cartographic scale that allows for generalizations or representations to be made, or both. The analysis scale allows for understanding real-world processes by defining methods. The three are central to the understanding of the natural world and phenomena. Due to this formulation, within physical geography scale is seen as

ontological as something that exists out there to be discovered or interrogated through methods. I now turn to human geography, where the contestation around scale arises.

2.1.2 Human Geography

The 'scale debates' characterize the intense intellectual debates around the concept of scale. This contestation was initiated due to the early reframing in the 1980s of the term by human geographers. During this period, the traditional definition was expanded from a measure of cartographic information to take on a socio-theoretical role, thus taking up greater significance in the social sciences. In essence, this reframing has several implications. One implication is that understanding the operations of social processes entails understanding differences across different scales such as the local, regional, national, and global. This implication would mean scale is foundational to understanding society. The other implication is that if 'geography matters,' then understanding society entails also understanding the spatial.

As argued by Jones, scale theory arose and developed as a component of the sociospatial dialectic. As it maintains that social processes simultaneously create and are products of space, the socio-spatial dialectic became an influential theory(Jones, 2017). Scale as a concept was developed further under this theoretical lens; however, critical geographers were unhappy with its orientation towards economist, materialist, and structural Marxism frames. The poststructuralist turn questioned scale's ontological's status. As Jones states:

"Indeed, under poststructuralism's "crisis of representation," questions arose as to whether scale is, in fact, an ontological bedrock of social space or merely an epistemological framework that we impute to space to help provide order and meaning. The local-to-global scaffolding upon which scale was initially theorized was challenged by such nonhierarchical theories as found in Gilles Deleuze's and Félix Guattari's philosophy and Bruno Latour's actor-network theory(Jones, 2017)."

The ontological versus epistemological divide resulted in a wealth of scholarship, with some advocating for the concept as being ontological, while other scholars argued the epistemological case. In contrast, others called for the complete abolishment of the term in the discipline. The first scholar who advanced a theory of scale based on the sociospatial dialectic was Peter Taylor. Taylor argued that political economy should be the theoretical basis for the field of political geography. He emphasized that the basis for building this body of work is scale(Taylor, 1982). Given Taylor's materialist grounding, he introduces what he calls the "political economy of scale" with three vertical layers of stratification. The three levels are "the scale of reality(global), the scale of ideology(state) and the scale of experience(urban)(Taylor, 1982)." The linkage between geography and the political is seen as the common perspective through which we understand scale.

Another scholar whose seminal work has had a significant influence on the scale debates is Neil Smith. In his book, *Uneven Development*, Smith builds on the spatial dialectic to argue that scales do not simply exist as givens but instead are at the heart of uneven development under capitalism(Smith, 2008). Smith agrees with Taylor that scales

exist at the three levels of the global, the nation, and the urban scale; however, they diverge on two-minute details(Jones, 2017). One divergence is that Smith sees scale as a product of capital where capital is bound to space. This view is similar to Harvey's argument on spatial fix where capital needs sites to occupy materially in the real world(Harvey, 1981). This position is different from Taylor's, as Taylor sees scale as not only relational but political. The second point of divergence between these two is that though Smith agrees to the three levels of "the political economy of scale," he is against ascribing to the respective levels specific and related social processes.

After Taylor's and Smith's work, the second wave of scholarship is the introduction of the "politics of scale." Through this wave of scholarship, several scholars argue scale is not only a product of capital but most importantly, scales can be strategized and contested over. Work by scholars such as Agnew showed how political parties in Italy organized around scale levels(Agnew, 1997). Others, such as Miller, focused on social movements and their scalar strategies(Miller, 1994). However, it was not until Swyngedouw's work on scale as a form of distributed power that another wave of scholarship was born. Swyngedouw argued that scales could be seen as constantly transforming and sometimes counter-cultural in social-spatial power struggles(Swyngedouw, 1997). These geographic structures(scales) are a collection of interacting and nested scales temporally produced.

The turn towards scale as a dispersed notion of power resulted in a departure from the urban, nation-state, and global as exacting scales. This turn birthed changes that position scale as vertically produced and horizontally produced by social networks. Smith's work

on “scale jumping” and “scale bending” is evidence of the view on the malleability of scale. “Scale jumping” for Smith refers to how the expansion of political power at one scale could extend to another(Smith, 2004). On the other hand, “scale bending” refers to the upending of implicit assumptions on what activities fit specific scales. Other than the change on scale malleability, some scholars argue that scales and networks provide a better framework when considering both at the same time. In this case, scale is not just a series of vertical levels, but scale should also be evaluated horizontally through networks. Scholars such as Cox illustrate how scale is dependent on “networks of association,” evidenced by the role capital cities in local states play(Cox, 1998). Others, such as Brenner, argue that the malleability on scale(non-rigid) is due to the rise of globalization(Brenner, 2001). He argues that rather than view globalization as mono-directional global forces that act on sub-global realms, globalization is a reconfiguration and re-territorialization of superimposed scales. For Brenner, scale is relational and intrinsically linked to hierarchies and dispersed across different cross-scalar networks. Leitner, also focussing on globalization, argues for viewing scale and networks by integrating both vertical and horizontal networks(Leitner, 2004).

Nothing is perhaps central to the scale debates as Marston’s work where due to the move from rigid structures of scale to more malleable one’s other smaller scales are put forth. Geographers such as Marston argue that scale is a social construct that organizes capitalist production and extends to social reproduction and consumption(Marston, 2000). She presents the household as a scale where social reproduction occurs. She argues that within capitalism, social reproduction involves not only large physical

infrastructures of capitalism, such as the delivery of services such as schools, roads, but also the small scale social, physical, cultural, and emotional infrastructure of the household where labor power is reproduced daily. Marston also argues that in addition to the household as a site of social reproduction, the household is also the scale where the ingraining of capitalist consumption practices occurs.

In his response to Marston, Brenner argued for "a more precise and analytical conception of geographic scale(Brenner, 2001)." On this, both scholars agree (on a more precise definition)(Marston and Smith, 2001). Brenner further argued that the "politics of scale" refers to the production, reconfiguration, and contestation of the scalar differentiations, orderings, and hierarchies. He states:

"In this plural aspect, the word 'of 'connotes not only the production of differentiated spatial units as such, but also, more generally, their embeddedness and positionalities in relation to a multitude of smaller or larger spatial units within a multitiered, hierarchically configured geographical scaffolding. The referent here is thus the process of scaling through which multiple spatial units are established, differentiated, hierarchized and, under certain conditions, rejigged, reorganized and recalibrated in relation to one another. Here, then, geographical scale is understood primarily as a modality of hierarchization and rehierarchization through which processes of sociospatial differentiation unfold both materially and discursively(Brenner, 2001)*."*

Marston et al. followed up by arguing that Brenner was unlikely to find the tools for analysis by maintaining boundaries between the production of scale and the more expansive social production of space(Marston and Smith, 2001). She added that "scale is a produced societal metric that differentiates space; it is not space per se." For her, "geographical scale is not something imposed on space but rather that the production of scale is integral to the production of space." This theoretical reframing towards the social construction of scale within human geography is based on Lefebvre's theories on the production of space(Lefebvre, 1991). Other than making a case for scale as a social construct, Marston also argues that scale also refers to the measurement or level of resolution as large scale studies incorporate coarse resolution, and small scale studies incorporate fine-grained resolution(Marston, 2000). Building upon Howitt's work, who argued for seeing scale as relational, Marston argues for understanding how the constitution of scale and its transformation around social-spatial dynamics(Howitt, 1998).

Howitt makes a case for scale as possessing three facets: size, level, and relation. He finds the first two facets problematic as alone they oversimplify scale. On the other hand, relation complicates the notion of scale, thus arguing for understanding scale as a factor in the construction and dynamics of geographical totalities rather than merely geographical relations(Howitt, 1998). Marston, building on Howitt's characterization of scale, summarizes the academic work on scale as comprising three core tenets on scale production. The first is that scale is not an external fact awaiting discovery but rather a way of framing conceptions of reality. Under this framing scale is not an ontological division between home and locality, urban and regional, national or global. Instead, the

differentiation of geographical scales establishes and is established in geographically structured social interactions. Secondly, is that the outcomes of these framings are tangible and have material consequences. Lastly, the framings of scale are often contradictory and contested and not necessarily enduring(Marston, 2000).

At the end of her seminal work on the social construction of scale, Marston questioned scale's ontological status entertaining the rejection of scale as a concept(Marston, 2000). This proposition echoes one that was made earlier by Katherine Jones on the epistemological status of scale(Jones, 1998). Marston et al. followed up on this proposition by arguing that it is impossible to obtain analytical specificity as earlier debated as the concept is causally deficient. They made their argument by illustrating the difference between horizontal networks and vertical geographies of scale as dependent on the reflexive position of the researcher. For them, this was about spatial imaginaries brought about by the researcher's position compounded by scalar theorizing that has focused on globalization, economics, and politics. They add, "political and economic geographers have tended toward macro pronouncements that assigned the global more causal force, assuming it to be more orderly relegating the local to the status of the case study(Marston, Jones and Woodward, 2005)"

In considering an anti-scale analytical framework, Marston et al. put forth site ontology as a useful approach for moving away from hierarchy and attending to the unique conditions at every site(Marston, Jones and Woodward, 2005). Site ontology is a form of flat ontology similar to Latour's actor-network theory, object-oriented ontologies,

or theories of assemblage where they conceptualize ‘sites’ as immanent(self-organizing) event spaces dynamically composed of bodies, doings, and sayings. For them, horizontal network approaches fall into the same trap. The tendency for the spatial abstraction of transcending levels in the vertical form is replicated in the horizontal where flows take up hierarchical forms. This horizontal turn is what they consider ‘flowsterism’ based on the idea of ‘spaces of flows’ put forth by Castells(Castells, 1993). Smith is also critical of Castell’s ‘spaces of flows’ as he sees it as a fetish turning to call for a duality of spatial fixity and fluidity as it allows for seeing the malleability of scales(Smith, 1996). Like Smith, Brenner makes a case for seeing scale as not only through vertical hierarchy but also horizontally through ‘interscalar’ networks(Brenner, 2001).

While arguing for a site ontology, Marston et al. critique the approach of having a hybrid approach to scale that considers vertical hierarchy and horizontal networks of socio-spatial processes as deficient(Marston, Jones and Woodward, 2005); they provide several reasons why the hybrid approach falls short. One reason is the ambiguity of the term scale as depicting areal coverage (that is horizontal), also known as size and scale as a level illustrating hierarchy. This ambiguity is still a matter of intense debate as no one has managed to wrangle the two together. Marston et al. argue that the conflation of the two frames is obscuring when differentiating them as scale. They argue for the discarding of this distinction. The second reason is what they call the ‘Trojan Horse’ made present due to the difficulty of disentangling spatial hierarchies. This difficulty is due to the binaries that emerge from this approach. Binaries such as the micro/macro or the local/global distinction they argue are emblematic of this approach. The oppositional

thinking engendered by this approach brings about atomistic versus holistic thinking, in turn, affecting other fields. For instance, an example they provide, in politics, liberalism versus conservatism is seen through the lens of global cosmopolitanism against localisms such as tribalism or patriotism, among others. Theoretical delineations are also established, such as abstract versus concrete, theoretical versus empirical, nature versus the artificial. Of particular interest in this debate is the literature around the local versus global. In the next section, I turn to the discipline of globalization studies to highlight how globalization studies have studied scale.

2.1.3 Globalization Studies

This section delves into the discourse and academic literature around both the global and the local. Specifically, I situate the literature specifically within the context of scale though in generic terms, discourse on globalization and localization centers scale. As highlighted earlier, two main ways characterize the discourse around scale in the context of globalization. One is the move away from the local, global dichotomy. This critique is based on the debate around a vertical hierarchical scale and the challenges in characterizing agency. The second way is the criticism of "flowsterism," where flows demarcate scale(Marston, Jones and Woodward, 2005). Framings and perspectives around scale have influenced the discourse around globalization. In responding to Jones and Marston, Jonas argues that they focus on the global versus local dichotomy failing to recognize the other middle-level scales present(Jonas, 2006). Jones et al. counter Jonas by arguing that they present the middle-scales as mechanisms of showing how scale is a limiting concept(Jones, Woodward and Marston, 2007). They further argue that rather

than focusing on the levels or the complexities in between, focusing on the binarizations that are endpoint associated is what is essential. However, in my assessment, though I also argue against such binaries, there is a need to recognize that endpoints are socially constructed. Endpoints are not cast in stone but preferably present relative tools in thinking through scale. In the sea level sensor project, other planetary forces come into play, which may not be considered global. Despite the movement of the sun, the moon, and the gravitational forces exert agency, most discourse around the global and the local stops at the earth-bound level. Our experiences of the agency of all the forces and the things above are also remarkably different. In addition, we never seem to give the moon a greater agency than the local. Another point to emphasize on scalar endpoints as socially constructed is the heterogeneity when referring to the local. The local is not fixed as a scale, though when used in language, it refers to the sites and scales where specific processes occur. The local could refer to the household scale, the neighborhood scale, among many other lower-level scales.

Similarly, as argued by Kearns, part of thinking through scale is maintaining the language of hierarchy. Kearns argued that events occurring at one level provide the conditions for other events at other levels, thus creating hierarchies(Marston, Jones and Woodward, 2005). He provides the example of parliament where we could consider events occurring at parliament as national. Moreover, a parliamentary system's products create conditions for other possibilities or constrictions at lower scales such as the neighborhood scale. The use of language in describing globalization also points to the interpretation of local-global binaries. For instance, the term 'touching down' is used to

describe seeing the local in the global(Massey, 1994). Others such as Swyngedouw have introduced terms such as ‘glocalization’ arguing for a recasting of globalization as a twin process of institutional arrangements being rescaled(scaled-up) to supra-national levels and at the same time downscaled to local scales of the individual body and cities(Robertson, 1995; Swyngedouw, 2004). Jessop and Sum taking on a similar argument, introduced the term ‘glurbinization’ referring to how local cities take advantage of their place-based competitive advantages to marshal capital and spatially fix it in place(Jessop and Sum, 2000).

Within the discourse around globalization, there has been increasing academic work on the local and localization. Local research focuses on highly situated sites and highlights the effects of global connections to local places. Often the local is framed as the site where processes occur or should occur. In the case of sustainable development and ecological management, it is common for the positioning of the local as the right scale. Scholars such as Purcell warn against making the local as the unique site where processes occur or should occur(Purcell and Brown, 2005; Born and Purcell, 2006; Russell, 2019). He refers to this as the local-trap where local-scale decisions and interventions are seen as inherently better as they are seen to bring about social justice and having sustainable ecological outcomes. Massey makes a similar argument insisting that just as the local is seen as concrete, grounded, and real, so too is the global(Massey, 1994).

In this section I have detailed the debates around scale in geography. I argue for a hybrid model as the assumption on vertical hierarchies is seen as universal. I draw upon other scholars such as Horton to demonstrate why scale as a concept is necessary. I now turn to the topic of scale and temporality.

2.2 Scale and Temporality

Unlike in geography, the concept of scale is not as contested when referring to the temporal. Though there is an acknowledgment on the temporal scale as socially constructed and therefore epistemological, the discourse around the concept is not contested, especially as a form of ordering(Adam, 2002). In addition, as argued by Adam, time is perceived differently in different cultures. However, unlike other cultures such as the Nilotic Nuer, the critical difference is that time is "not an objectified spatialized quantity made up of discrete instants following each other." She states:

"Western time emerges from these two studies in association with a number of clustered characteristics: as an abstract, spatialized quantity that is divisible into single units; as a two-dimensional, linear, directional flow or succession of constant rate that extends from the past to the future (or vice versa); and as something that passes or can be saved, sold, or wasted."

Adam criticizes anthropological practices that are not reflexive enough, especially when considering time and temporality. This criticism is because anthropological studies mostly placed other communities with different perspectives of time as non-linear and

non-quantified. She makes her case showing the social construction of time, including in Western societies leading to other scholars building upon her work. Her argument points to a conflation of temporality and time as understood through clocks(Adam, 1994). In the next section, I dedicate some time to explain the social construction of time.

2.2.1 Social Construction of Time

As highlighted earlier, Adam made a case for viewing time as a social construct. For her, time is omnipresent and invisible though social and spatial research has taken it for granted. The taking for grantedness is perhaps why a false dichotomy of 'traditional' versus 'modern' societies has developed. The failure on the part of anthropologists to be reflexive on how they may impose temporal categories on sites and subjects under study resulted in this dichotomy. Most social science research had focused on conceptualizing time as an arrow, a cycle, or a rhythm that could be linear, coherent, or fragmented(Besedovsky *et al.*, 2019). In the modem framing of time (or rather the unquestioned understanding of Western time), time is seen as abstract, quantified, spatialized, and reified through clocks and calendars. It is this understanding that Adam challenges to show that Western notions of time also include non-abstract, qualitative forms. An example of such a non-abstract form is the discourse around the question 'when.' In this specific case, she addresses the 'when' question as used in the English language. She states:

"All types of 'when time' could entail considerations relating to clock and calendar time, but these are never the only ones. The rhythms of nature and the seasons, social

norms, traditions and habits, physiological changes, knowledge of the past and anticipations of its consequences, all are brought to bear on calculations about the future. They all come together and become inextricably interwoven in judgements about what constitutes the 'right' time to engage in certain activities. While the existence of clock time facilitates con- text independence and global standardization, decisions about the timing of even the most habitual of actions are made on a one-off basis and with reference to a particular context. 'When time', we can conclude, exists in all socie- ties. In its particular expressions, however, we find that some clusters of sources are shared, while others are culturally unique. Neither quantity nor quality, neither society nor nature, neither the clock nor the routine of tasks seems to furnish the single source for any specific cultural expression. It therefore makes little sense to contrast the time of traditional cultures with Western industrial time along these lines."(Adam, 2002)

When scholars discuss time's social construction, the implication is that it is highly context-dependent and influenced by culture. However, scholarship until then had reduced time and temporality to clock time, which refers to the quantifiable, abstract notion of time. Time is multifaceted. To be able to speak about a 'good' time, one needs to go beyond the abstract form of time measured by a clock or calendar. On the other hand, temporality comes to the fore as it is centered on processes and fundamentally refers to cyclical unidirectional irreversible change. Tempo refers to the speed of the timing and temporality of processes. All these three, timing, temporality, and tempo, play central roles in our understanding of time. In the next section, I now detail some of the

scholarship around clock time as it constitutes a standard framing on how the fields of Anthropology and STS have studied temporality.

2.2.2 Clock Time

Several scholars within STS, history, and anthropology have studied the role of the clocks as technology in society(Giddens, 1979; Adam, 1994; Mumford, 2010; Nowotny, 2016). Clocks are falsely associated with a shift in how time was understood historically. This false association is evident as the clock is given an outsized role while failing to acknowledge the social-cultural moments and events building up to the clock and its use as a technology. Adam highlights how many societies arrived at calendrical systems without the clock. She provides the example of Stonehenge, which served a calendrical function around 1800 BC. Ancient Egyptian water clocks and early Chinese mechanical clocks that could be considered predecessors to the Western clock are other examples that she provides.

The earliest form of what is considered the modern western clock is the development of the pendulum that is mechanical in nature. The pendulum played an essential role in establishing a uniform artificial time standard. The indexing of its regular oscillations onto a numbering system brought about temporal abstraction. As a unit of measure, its abstraction made time(clock time) to be context-independent, precise, and invariant(Adam, 2002). Lindley argues that clock time is abstract, interchangeable, and generic(Lindley, 2015).

As an interchangeable commodity, power relations made present by time and temporality surfaced. For Giddens, time is the medium through which labor is extracted and abstracted to an exchange value(Giddens, 1979). As Adams points out, the labor disputes historically were mainly caused by elements of this abstraction. Issues such as the actual value, the tempo or rate of work, and over time, among other issues, could be traced to the clock. Besedovsky et al. also argue, temporalities are not only plural, but they are also political and politically shape society in different ways. For them, understanding the ordering effects of temporalities entails understanding the creation of the temporalities by power relations and also the power effects produced through their ordering(Besedovsky *et al.*, 2019). For instance, scholars such as Bear show how some temporalities come to dominate others, specifically through the colonialist projects(Bear, 2014). Others point to the domination of Western time over the rest of the globe(Barak, 2013; OGLE, 2013). At a national level, temporalities are made present by the state, such as when schools close and open or at a more local level when the municipal authorities pick up trash(Lemke, 2000). As evident in the examples, scalar orderings may form temporalities. Additionally, the ordering of different scales(spatial) could come through temporalities.

As mentioned earlier, the oversized role given to clock time is attributable to its role in capitalist structures and, more specifically, in the role of the clock in the industrial period. The mechanized clock is placed at the center of the industrial period as it enables the establishment of industrial rhythms(Mumford, 2010). As Lewis Mumford states in his text, Technics, and Civilization:

"Abstract time became the new medium of existence. Organic functions themselves were regulated by it: one ate, not upon feeling hungry, but when prompted by the clock: one slept, not when one was tired, but when the clock sanctioned it. A generalized time-consciousness accompanied the wider use of clocks: dissociating time from organic sequences.."

Mumford continues to make the link between the abstraction of time and its connection to capitalism. He continues:

"This last fact was particularly important for life and thought: the quest of power by means of abstractions. One abstraction reinforced the other. Time was money: money was power: power required the furtherance of trade and production: production was diverted from the channels of direct use into those of remote trade, toward the acquisition of larger profits, with a larger margin for new capital expenditures for wars, foreign conquests, mines, productive enterprises... more money and more power. Of all forms of wealth, money alone is without assignable limits."

For Mumford, the time's abstraction reinforced the forces of money. Other scholars make similar arguments on the commodification of time(Thompson, 1967) and its relation to capital(Giddens, 1987). I now turn to the next section to illustrate different temporalities and understandings of time divorced from the clock as a technology.

2.2.3 Non-clock Temporalities

Several scholars that embrace the move away from clock-based time have provided different perspectives of time and temporality. Within social theory is the place of social time introduced by Durkheim, who debates the epistemological nature of time and the category of times in tandem with categories of space and causality(Durkheim and Swain, 2014). Durkheim argued that it was the 'rhythms of social life' that form the basis for categories of time. This discourse was made prevalent due to efforts in distinguishing social time from astronomical time. Unlike clock time, which is easily distinguishable from astronomical time, the same could not be about social time. Days and nights in the astronomical sense are not constant. Variations based on place and other astronomical factors end with an imbalance between night and day. Clock time, on the other hand, is context-independent, designed for measuring constant intervals(Adam, 2002; Lindley, 2015).

Building on Durkheim's framing of time, Sorokin and Merton argue that social time is qualitatively heterogeneous and not quantitatively homogenous(Sorokin and Merton, 1937). They characterized social time as being grounded on collective social activities resulting in local time systems. These time systems engendered synchronicity and coordination of local activities resulting in common time systems. In this frame, scholars challenge the view of time as uniformly flowing. For social theorists and sociology, this birthed a debate around the role of time in social theory and largely the view of time as neglected in social science research(Nowotny, 1992). Since then, there has been a wealth of literature on time and temporality within the social sciences.

Other than the understanding of the heterogeneity of time, perhaps the plurality of time and temporal scales was the next central perspective that changed in the social sciences. Nowotny introduces the term 'pluritemporalism' to highlight the acknowledgment of the different temporal modes of social time(Nowotny, 1992). Understanding the production of time also entails understanding the construction of different temporal pluralities. As Besedovsky et al. emphasize, a plural frame allows for one to see natural time and social time and other social temporalities and their accounting in different temporal geographies(Besedovsky *et al.*, 2019). Building on Zerbavel's point of how social-temporal patterns are mostly seen as rigid despite being products of social behavior, Orlikowski and Yates build on the argument to state that time is plural. However, this plurality may be experienced as objective, quantitative but may also be subjective and situated(Zerubavel, 1985; Orlikowski and Yates, 2002).

Several scholars have developed different approaches to seeing or analyzing the construction of time. A common thread, especially in anthropology, is the study or observation of routines. Wilk considered how the cultivation of routines becomes naturalized, turning events into precedents for new routines(Wilk, 2009). Orlikowski and Yates argue for seeing distributed collective practices as rhythms. For them, rhythms not only shape collective action but are also shaped by collective action(Orlikowski and Yates, 2002). The framing on rhythms is based on Reddy et al. seminal piece on information seeking in medical work(Reddy, Dourish and Pratt, 2006). Others such as

Marston, though focusing on space, make a case for events as ways of understanding scale(Marston, Jones and Woodward, 2005).

Building on the plurality of time, several scholars have detailed other temporal scales and temporalities. Take the case of Michael Young, who uses chronobiology to show how natural, biological rhythms and human schedules might complement each other to escape the 'metronomic society.' A 'metronomic society' is characterized by Young as a product of the industrial revolution that brought about the compulsion to carve up time into continuous and monotonous "rhythms that are opposed to those of nature." This carving up has created what he calls a "time famine" at both the individual and welfare state levels where that which cannot be time rationed, thus making its provision impossible(Young, 1988). Part of this segmentation and understanding of time is based on linearity made possible through advanced time measurement.

Similar to Young, others have highlighted the temporality of natural systems. Take the case of Karasti et al. in her work on infrastructure, where she mentions natural time as describing the temporality of natural rhythms(Karasti, Baker and Millerand, 2010). Contrastingly Jackson et al. argue against using natural time but instead use phenomenal time(Jackson *et al.*, 2011). Phenomenal time allows for reflexivity, allowing one to see how the study or understanding of such phenomena is shaped and constrained by the temporalities at play. This formulation of phenomenal time and rhythms moves away from a view of time as being objective as they too could be acted upon. As mentioned earlier in passing, another form of temporality or framing of time is astronomical time.

Biographical rhythms constitute another form of temporality. Jackson et al. highlight the biographical rhythms needed in doing collaborative work, especially in infrastructures. Part of collaboration is the synchronizing of bodies even though they may be present in different temporal localities. Additionally, part of social time entails dealing with biographical rhythms. For instance, take the example of the classroom, as highlighted by Lemke(Lemke, 2000). Students have to go to class and structure their being in the classroom based on school schedules.

I now turn to highlight scholarship on temporality in digital and in infrastructure studies. Karasti et al. argue that digital or Internet time is based on actors that associate with digital technologies(Karasti, Baker and Millerand, 2010). Though they mention the idea of digital time in passing, it is the literature view by Lindley that she introduces a wealth of perspectives on digital time. Building upon literature within STS and CSCW, Lindley argues that digital time is a framing that centers Western time where "technology is implicated in the speeding up of everyday life.' She builds the argument on the speeding up of life by referencing Rushkoff's work, highlighting the disconnection of computers from the everyday personal and collective rhythms(Lindley, 2015). Rushkoff argues that speeding up is made evident through the experienced need to be continuously connected as continual change is made visible through technological systems such as social networking sites(Rushkoff, 2013). This way, the flow of information is seen as always and instantly available.

A similar argument on speeding up brought about by technology is Tomlinson's argument, which states that as speed is central to modern cultural practices, there is an emphasis placed on immediacy(Tomlinson, 2007). Through electronic media, speed is inherent and taken for granted. Other media studies scholars such as McLuhan make similar arguments on the annihilation of time and space(McLuhan, 2005). However, regarding digital time, Lindley makes a more nuanced argument about digital time. She states:

"In these analyses of plasticity we see how, like clock time, digital time is not simply a property of technologies, nor does it straightforwardly emerge as a sociotechnical convention associated with their use. Rather, it has coevolved with broader shifts in the temporality of everyday life, such as the emergence of fractured rhythms, and the associated need to fill the gaps between them(Lindley, 2015)."

Lindley's argument is similar to the one I highlighted earlier, where the clock is not just a measure of time but also coevolved and defined social rhythms. However, in her case, she is making the argument based on digital time and how everyday life is affected or changed by naturalized digital rhythms. For example, she draws us to a temporal frame christened plastic time described as "the negative space of busyness." She builds on this notion of plastic time based on the work of Rattenbury et al., who established that Internet use is an excellent filler for plastic time(Rattenbury, Nafus and Anderson, 2008). For Rattenbury et al., plastic time is unanticipated, un-reflexive, and fluid and is basically gaps in the schedule. Internet use as a form of plastic time meant that it is an activity that

could be easily interrupted, resumed, and not of high priority. The asynchronicity in Internet use is what is important to notice despite the common framing of the immediacy or instantaneity of the Internet and related technologies. Other scholars such as Irani make similar points though their focus is on television use(Howard, Kjeldskov and Skov, 2007; Irani, Jeffries and Knight, 2010).

Interestingly, McLuhan pointed to the television's role in replacing the fireplace and viewed through Marston's work on scale relationships similarities abound between the works produced by both. The homestead demarcates a scalar position as stated by Marston, and through the television, the realignment of biographical, clock time, and collective family temporal rhythms occurs. Scalar implications here abound—for instance, the development of television programming where a public schedule brings about a collective experience. Also, the provision of television products through several channels points to the scalability of the television medium, allowing one to move from one set of temporalities to another.

Like television programming and in specific live television, the sense of immediacy is also present in digital technologies. As Irani highlights, other technologies such as the VCR altered temporal rhythms as they allowed for plastic time. However, discourse around the character of the sense of immediacy differs. Lindley makes a case for 'the impression of nowness' as describing the sense of immediacy and the present within social media that is upheld through an interface and social connections in part(Lindley, 2015). Schofield and Arrigoni, in discussing the temporalities made present in networked

infrastructures us the term liveness to describe the ‘inevitable passage of time regardless of what the user does, like in World of Warcraft or the live broadcasting of the Super Bowl(Schofield and Arrigoni, 2017).’ In both forms, the heterogeneity of temporality in digital infrastructures varies. In my dissertation, I highlight some of these digital time temporalities, such as latency and technologies like caching that act as a web-based VCR.

Within infrastructure studies, several scholars have highlighted the different frames of time and temporality in different infrastructures. Take the case of Jackson et al., who argue for the organization of collaborative scientific work around four rhythms or registers of organizational, infrastructural, biographical, and phenomenal(Jackson *et al.*, 2011). Through these four rhythms, scientific collaboration is achieved by continually aligning and realigning. Though they consider them rhythms and not temporalities or times, they provide a good framework for understanding temporality in collaborative scientific work. Karasti and Baker refer to this aligning as articulation work(Karasti and Baker, 2004). Zerubavel’s work, though not grounded in infrastructure studies, is seminal in computer-supported collaborative work as it describes a ‘temporal division of labor’ where members may collaborate in different forms even though they are in the same temporal order(Zerubavel, 1985). Characteristically, actions may be coordinated but not collocated. Lindley builds on this notion to argue for designing for temporal experiences as being collective and entangled, especially as the digital enables a different form of collocation. She states:

"This point ties into the conceptualisation of time as collective [29] and entangled [43]. The infrastructure that supports a 24/7 society is one that relies on people as well as technologies, the conventional nine-to-five work rhythm, for example, being underpinned by people working shifts outside of these hours. Grappling with these broader temporal infrastructures necessitates a close inspection of the multiple temporalities that exist within cities and neighbourhoods, and the ways in which they are interwoven and cross-dependent. Initial approaches to research and design in this space could include making these infrastructures visible and facilitating possibilities for connection across the temporal boundaries that are inherent to them(Lindley, 2015)."

Though Lindley does not make a bold claim for time is/as infrastructure in the excerpt above, she comes close to describing time as such. She ascribes to naming infrastructures that maintain and sustain collaboration by characteristically referring to them as temporal infrastructures. However, Besedovsky et al. make a more forceful argument for seeing time as infrastructure to the point of highlighting how time as infrastructure maps onto the dimensions of infrastructures, as highlighted by Star and Ruhleder. As they state in their piece:

"Beyond definitions that focus on the material characteristics of infrastructures: they are structures that underlie and powerfully shape current forms of social organization and interaction. Considering time through this analytic promises to elucidate the ways in which political, social, and economic conditions shape and exert authority over the

everyday urban, and the material and social effects of such dominations(Besedovsky *et al.*, 2019)*."*

The view of infrastructures as political is now new. Take the case of Winner's piece on the politics of artifacts as a case and example(Winner, 1980). Similarly, infrastructuring and infrastructures are not only social but also carry economic implications. However, using an analytical lens of time as an infrastructure enables us to see how infrastructuring comes about partially. Take the case of infrastructure time and project time as temporalities that Karasti highlights to show the difference between the long-term work in infrastructures versus short term work. For Karasti et al., part of the process of infrastructuring is balancing the long term and the short term. The long term is achieved through maintenance and sustainability, while the short term is based on immediate project needs(Karasti, Baker and Millerand, 2010). Similar to Star and Rudleder position that an "infrastructure occurs when the tension between the local and the global is resolved" they state:

"An infrastructure occurs when the tension between short-term and long- term is resolved. That is, an infrastructure occurs when here-and-now practices are afforded by temporally extended technology that can be used in an everyday, reliable fashion. Infrastructure becomes transparent when it exists as an accessible, ready-to-hand installed base that enables envisioning future usages(Karasti, Baker and Millerand, 2010)."

Karasti et al. argue that an infrastructure occurs when the tension between the long-term and the short term is resolved. I argue for considering the different temporal scales at play and how alignment occurs, and tensions are resolved across scales. Moving away from a short/long or local/global dichotomy helps denaturalize such and similar dichotomies. Also, the long-term is relative. For several infrastructure studies scholars, infrastructure is long-term and needs to attend to the "long now"(Edwards *et al.*, 2007; Ribes and Finholt, 2009). For Edwards, the long now in the development of cyberinfrastructures(a form of information infrastructure) is 200 years(Edwards *et al.*, 2007). This move towards considering the long term is emblematic of scholarship (within infrastructure studies at least) that has primarily focused on the short-term. Though I encourage the movement towards addressing issues of the long now, I argue that infrastructure entails much more than resolving the tensions between the short-term and long-term. By drawing on Lemke's perspectives on social theory, I argue that infrastructuring is much more than resolving tensions, but also entails aligning some temporalities and creating others. These temporalities inevitably become embedded with the infrastructure.

In the next chapter, I now turn to the discourse around scale and the Anthropocene as it is a compelling discourse as it is not centered on geography nor temporal concepts though it does engage with them.

2.3 Scale and the Anthropocene

The word Anthropocene was introduced by Eugene Stormer and later popularized by Paul Crutzen in 2000(Crutzen and Stoermer, 2000). As Diogo et al. highlight, the debate has centered around its meaning, utility, its epistemological, and conceptual framing(Diogo, Louro and Scarso, 2017). The term emerged as important to both the humanities and the sciences for understanding the long-term human impact on the Earth through the notion of a potential new geological epoch. The Anthropocene commonly referred to as the "Age of Man," presents us with two pressing questions. Questions of the when and who are part of the continuing debate. The former interrogates the beginning of this "Age of Man," while the latter interrogates responsibility for this epoch. Tracing the beginning of the Anthropocene is highly contested, and this is part of its contestation as a concept. Crutzen argues that the Anthropocene as an epoch started two centuries ago, coinciding with the design of the steam engine in 1784(Crutzen, 2006). The formal proposal by the Anthropocene Working Group suggests the post-war "great acceleration" in industrial development and radioactive fallout from nuclear experiments as the corresponding global geological marker(Crutzen, 2016). Others argue that the Anthropocene should be dated to the late 15th century when colonialism and global trading were the epoch's material and political preconditions(Lewis and Maslin, 2015).

The question of who is perhaps more contested than the question of when. This question goes to the crux of the matter when we speak of scale in the context of the Anthropocene. There is a collective realization that man has taken up a geological force of some form, thus characterizing humanity's actions spanning several time scales is

difficult. One main criticism of the term is the contextual collapse and its ahistoricity. The use of “we” and “us” as if humanity is homogenous, flat, and a free-floating reality is part of the problem(Diogo, Louro and Scarso, 2017). Some scholars consider the discourse on the Anthropocene as inherently emphasizing the urgency of a global solution for a global problem caused by humanity as a whole. The contextual collapse is made present due to the subsuming of socio-economic differences and political conflicts. Some of these scholars, such as Haraway, have developed alternative concepts to describe this epoch by highlighting capitalism’s role and its exploitation of natural resources. Colonial and Postcolonial scholars have also responded by highlighting how colonial science, technology, and medicine anchored a new worldwide epistemology(Chakrabarty, 2012). More fundamental to the question of who in the Anthropocene is the risk of strengthening the priority of human agency over non-human entities. This element of agency is at the core of the debate(Haraway, 2015). However, debates on agency are not just limited to discourse on the Anthropocene. Similar debates exist in discussions on temporal scales(Wilk, 2009; Lindley, 2015) and also on geographical scales(Marston, 2000; Jonas, 2006).

As mentioned earlier, one of the criticisms of a universal scale is that the human is centered. Several scholars have introduced different approaches to decentering the human. Haraway makes a case for a direct rearticulation of how we understand the “human” in the first place. She argues that through the liberal humanism model, we are likely to fall into the same trap as the Anthropocene, as currently defined, never fully accounts for the broad assemblage of non-human elements implicated. Chakrabarty looks

at the Anthropocene from the context of postcolonial studies. He argues that the age-old humanist distinction between natural history and human history has collapsed(Chakrabarty, 2009). The implication here is that geological time scales for the Anthropocene limit our understanding of both the human and the natural world. As a historiographer, he sees this collapse as a challenge on narrative form and how to write historiographies that merge these two subfields. The subfield of Socio-ecological Systems(SES), within environmental humanities, has also made efforts to incorporate non-human, human elements, and activities more accurately. The practice positions everything as part of a broader system. Some scholars have argued that the constituent components, social, economic, and ecological, should not be presented as interdependent pillars but rather as inseparable(Reyers *et al.*, 2018). Approaches to decenter the human have since taken different forms. Forms such as actor-network theories, flat ontologies such as object-oriented ontologies and site ontologies, assemblage theories, among several others. More on these theoretical frameworks later.

Entangled with the discourse around human agency in the Anthropocene is the concept of scale. Similar to the Anthropocene, the term scale is also contested across different fields. The term scale derived from the Latin word scala for ladder, step, or stairs enables a calibrated and useful extrapolation between dimensions of space and time(Clark, 2012). Clark argues that dominant modes of literary and cultural criticism are blind to scale effects. By drawing on the derangements of scale, he shows how artifacts such as posters on how to combat climate change have been reduced to the individual scale leaving out other activities that occur at a larger scale. He claims that the

management of global climate change is undermined by a globally dominant political system that is based on nation-states and individualism, thus occurring at the wrong scale. Similar to these global political governance issues, literary criticism is not spared as the standard modes of criticism also occur at the wrong scale. Chakrabarty also discusses the challenge of literary or historical criticism that can be nonlinear and also cut across several temporal scales. Within Literary studies, scholarship on storytelling that invokes scaler thinking is increasing. Several literary scholars have argued for storytelling that is nonlinear. Cordle and De Cristofaro highlight how visual representations of charts, graphs often shape our understanding of the Anthropocene and that narratives of the Anthropocene frequently draw on "seeing effects"(Cordle and De Cristofaro, 2018). Davis makes a similar argument asking for a rethink and redesign of timelines as a form of visualization as dominant modes of representing time through timelines categorizes them as linear(Davis, 2012). In the section on time and temporality, I explain why this is an issue. Houser makes a case for a state of abundant but contested information, which she calls "infowhelm" that has become an unexpected resource for artists in communicating environmental crises(Houser, 2020). Other scholars, such as Laura Perry, show how environmental graphic novels have made an effort in scale shifting(Perry, 2018).

Other than the discussion on scale and agency in the context of the Anthropocene, another discursive trajectory is the framing of scale reified as global versus local. The framing of the global and the local within human geography is part of how scale is defined or redefined—geographically seeing the world as scaled provides us with a sense

of the size of power relationships. Local is smaller than global, and the global as undermining other smaller scales such as the national and the local. At the technical level, scale refers to the ratio between the size of objects on the Earth's surface and their size when represented on a map. The term also describes an areal unit on the Earth's surface or the extent of a process's or phenomenon's geographical reach(Herod, 2011). In the latter description, the terms global and local take prominence. The global is positioned versus the local, resulting in a wealth of scholarship on these two scales. In 1995 the term 'glocalization' was popularized by Robertson to highlight the co-presence of global and local processes, challenging assumptions that these processes are distinct or in opposition(Robertson, 1995). Swyngedouw also recontextualizes globalization by arguing that the local actions shape global flows while global processes, in turn, affect local actions(Swyngedouw, 2004). I have spent some time introducing literature on the global versus local in the section on geographical scale. The 'local' has been extended to critical data studies by Loukissas, who argues that all data are local as they are created at a time and a place(Loukissas, 2019). D'Ignazio and Klein argue for data feminist practices within the same frame that include embracing pluralism(D'Ignazio and Klein, 2016). I argue that this positioning, global versus local, leaves out the middle interlocutors that enable the interaction between the local and the global. Be they objects or organizations. I draw on feminist perspectives of plurality to highlight issues of multi scales.

The local also brings forth other disciplinary entanglements. Within the environmental humanities, Heise argues that environmental discourse in the US often privileges the

local “as the basis for genuine ecological understanding.” She argues that this leads to the treatment of the “local” as more tangible, intelligible, and concrete than the global. She advocates for “eco-cosmopolitanism” as a corrective from a sense of place to a less territorial and more systematic sense of the planet(Heise, 2008). Criticism of the positioning of the local as more tangible and material is also put forth by Purcell and Brown who caution against falling into the ‘local trap’(Purcell and Brown, 2005). Even terms as ‘glocalization’ and ‘glurbanization’ speak to this framing of the local as material. Other scholars such as Levin operating within the environmental humanities discipline argue for the need to study pattern and variability change with the scale of description. He further argues for the development of laws of simplification, aggregation, and scaling. He bases his argument on the fact that there is no natural scale at which we study ecological phenomena. Systems generally show characteristic variability on a range of spatial, temporal, and organizational scales(Levin, 1995). The challenge presented by Levin entails the production of knowledge through generalizable concepts while operating at different scales. This generalization challenge has fundamental implications for modeling and methodology. Others have made the case that most models within environmental humanities fail to reflect the typical characteristics of the Anthropocene fully. Characteristics such as societal influences and interactions with natural processes, feedbacks, and system dynamics(Verburg *et al.*, 2016).

Discourse on scale and the Anthropocene demonstrates how these two terms are tightly related. Any discussion on the Anthropocene and its definition highlight the scale of human activity across space and time. As an epoch, it describes cumulative human

activities as being large scale to the point of morphing the world's very being. As mentioned in the chapter on temporal scale, an epoch is also a temporal scale as it represents a division of time that is divisible into ages. The large-scale cumulative effects of human activities have brought about different effects at different spatial resolutions on the spatial scale. Thus, for scholars within the humanities, environmental sciences, and STS, scale as a concept is highly cited. Especially for scholars from disciplines with an Anthropocenic focus, discarding the concept and its use seems strange.

However, before qualifying scale to discourse on the Anthropocene, I would like to contextualize the topic of human agency. Though I have spent some time highlighting the contestation on human agency, I delve into the relationship between agency and scale. Chakrabarty argues that the current state of globalization and global warming leaves us with the challenge of having to think of human agency over multiple and incommensurable scales at once(Chakrabarty, 2012). Verburg et al. argue for developing models that support solution-oriented research for the Anthropocene problems through novel system representations that focus on the representation of feedback between social-ecological systems across different scales and the representation of human processes(Verburg *et al.*, 2016). Part of this work entails incorporating human dynamics. Through this view, the solution is presented as an engineering problem where human dynamics or systemizing human actions into models would resolve big-ticket issues such as climate change. The case for introducing human dynamics is also made by Donges et al. (Donges *et al.*, 2017). Scholars such as Horton are critical of this view as the idea put

forth on the Anthropocene by Crutzen is based on a 'universal overview' of scale(Horton, 2017). He states:

"Leaving aside for a moment the circular nature of this "solution," it is nonetheless clear that Crutzen's and Stoermer's suggestion requires the systematic production of a totalizing vision of human and natural ecology, a data-driven, meticulously assembled overview of all processes involving or affected by humans. This overview, catalyzed by the self-reflexive charge of the Anthropocene but assembled through the protocols of scientific data collection and technological application (the inseparable interrelation of which is generally referred to as "technoscience"), places humanity in the driving seat of the planet's ecology, first as the unwitting inflicter of "stresses," and then, ever so swiftly, as the deliberate and self-assured inflicter of corrective management technique."(Horton, 2017)

Horton, just like other scholars such as Haraway, Parikka, Chakrabarty, argue for the decentering of man. However, there is a fundamental difference in how they approach this. For Haraway, thinking about a multi-species but inheriting its scale is one way of engaging with theoretical and practical approaches. For Chakrabarty, incorporating the natural but also thinking about human actions across several scales at once is the way to do it. Parikka suggests a move away from the Anthropocene to the Anthrobscene(Parikka, 2015). However, perhaps it is Horton's piece that I think is illustrative of issues of scale. Horton reframes the issue of the Anthropocene as one that is explicitly about scale. He makes his case by asking the question of "how do we meet

the challenge of the moment where we face destruction brought upon non-human and humans without resorting to a universal overview?" For Horton, such a universal overview leads to humans getting a guilty verdict only to place humanity back on an epistemological order. As mentioned earlier, this point goes back to the 'who' question.

The ordering of the role and responsibility of humans and non-humans in this epoch is part and parcel of this ongoing debate. Wood is critical of Chakrabarty's view that humans are the primary cause of the current environmental crisis, as Chakrabarty argues that we need to study human agency across multiple and incommensurable scales at once. In developing a scale critique that emphasizes the importance of non-human agency, Woods turns the subject of the Anthropocene from the human species to one of modern terraforming assemblages. On the matter of scale, Woods is also critical of Chakrabarty by arguing that the human is not scalable. He argues instead for scale variance as it refers to thresholds that constrain biophysical, technological, and social becoming, thresholds beyond which scale effects influence how we observe systems and how they work(Woods, 2014). By using scale critique and seeing the environment as a modern terraforming assemblage, we can better understand scale effects. Through assemblage and actor-network theories, we can decenter the human and take an anti-anthropocenic position.

Other than the ordering of the human and non-human when discussing the Anthropocene, the other contentious issue presented is how to ascribe responsibility when limited to the human. In this dialogue, humans are not equally responsible, especially

when dealing with issues such as climate change. Do peasant farmers in the global south have the same responsibility as those in developing countries who may deploy advanced farming machinery or practice industrial farming? Even states or territories that contributed to the industrial revolution may not be equally responsible for the ecological destruction that all collectively face. This merging of responsibility is what Clark calls 'derangements of scale.' On speaking about the 'derangements of scale,' Clark highlights the challenges of the scale of actions between individuals and the global environmental crisis. He argues that the concepts of agency, rationality, and responsibility are being strained or even begin to fall apart when generalizing simple actions as political. Clark further argues that this has led to a reduction of environmental issues into one coherent problem, dysfunction, or justice, resulting in an implosion of scales that implicated seemingly trivial or small actions with enormous stakes while intellectual boundaries and lines of demarcation fold in upon each other(Clark, 2012). The generalizations are perhaps why a possible trajectory is reframing scale as political. See the section on politics of scale in the section on the spatial.

In my understanding, similar to Clark's argument on the 'derangements of scale,' Horton uses the term scalar collapse(Horton, 2017). For Horton, scalar collapse is a technique where two or more scales are conjoined within the same medium. Access from the first to the second is made possible through homogenizing the different dynamics. A product of scalar collapse is a universal overview that takes in everything under a common logic. Take the example that Clark highlights in his piece on the responsibility given to the individual to tackle climate change rather than perhaps other higher-order

interventions. A great example here is the case of carbon foot printing, where individuals and some private corporations have taken up mechanisms of calculating their carbon footprint with the aim of being carbon neutral or participating in carbon offsetting programs. Scholars such as Reno highlight the issues with initiatives based on such systems as at one scale, they may provide self-objectification but, on the other hand, potentially lead to greater inequality(Reno, 2018). The complexity of climate change is reduced to a carbon calculation, thus taking complex relationships, abstracting them, and reducing them to something that stands for such relations. Besides incorporating the non-human, Clark suggests reading several scales at once by embedding actions in multiple and even contradictory frames at once.

Clark's piece has been criticized for advocating a form of 'hollow ecology'(Estok, 2018). Estok characterizes the dismissal of critical discussion on "the animal question" as one that leads to the foreclosing of the possibility of generating an ethical scale appropriate for the enormity of the problems we face in the Anthropocene. Estok argues that similar to the expansion of our spatial and temporal scale, so too have we begun to imagine agentic capacity as a scale that needs attention. Estok draws upon Woods' work on developing a scale critique that shows that the Anthropocene subject is not the human species but modern terraforming assemblages. The issue of scale and responsibility has largely been directed towards a politics of scale. As mentioned in the chapter on scale in geography, politics of scale reframes scalar entanglements as explicitly political based on their construction and constitution. Scholars such as Jon make a case for new theories of scale based on the actants and their responsibility in addressing environmental

degradation issues. Jon argues for cities as sites for doing earthly politics due to the politics of scale that is characteristic of urban centers(Jon, 2020). However, pitfalls abound here due to the possibilities of the local trap.

Though several scholars who operate within environmental humanities engage with scale, few such as Tong make the opposite case for doing away with scale. In his piece on ecology without scale, he builds upon Marston and others' work to take such a position(Marston, 2000; Marston, Jones and Woodward, 2005). Thalos also makes a similar argument based on metaphysics for doing away with a one scale universe as the universe is scale-free(Thalos, 2013). For Tong, the problem of scale is that it is often seen as an ordered totality enabling zooming in and out. In a sense, he is critical of scale's universal vision and hierarchy. This is a similar view though fundamentally differing from Horton. Horton does not argue for doing away with scale but rather understanding the multiple differentiated scales while moving away from a totalizing scalar ladder. He sees the "Anthropocene as calling for an ecological cosmic view that is apprehensive of scale that avoids a totalizing vision and individualized subjectivism(Horton, 2017)."

On the matter of a universal scale, Zylinska argues for the need for a universal scale. For her, to consider a form of minimal ethics for the Anthropocene, a universal scale is needed. Through a universal scale, the universe's shared materiality is foregrounded as it serves as a point of unity in the ongoing process of unfolding matter across space and time. By bringing back universal scale, it serves as a reminder to us on the limits and excesses of our world-making (I delve deep into the issue of zoom in the next chapter as

zoom is related to scalability). Scale, for her, is not an "objective measuring stick that can be applied to space and time but rather part of the phenomenon it seeks to measure"(Zylinska, 2014). Scholars such as Jue draw upon this framing of scale to theorize scale through the medium of river water showing how scale theorizing runs aground when water is muddied(Jue, 2017).

In the next section, I make the link between scale, the digital, and infrastructure studies. I also take some time to highlight scalability as we cannot have scalability without scale.

2.4 Scale and Infrastructures

In this section, I take a turn to focus on the relationship between scale, scalability, and infrastructures. In the infrastructure studies realm, I focus on information infrastructures and digital infrastructures due to the prevalent view of the digital as easily scalable or perhaps for some without scale. However, within infrastructure studies, infrastructures are considered sites where resolving tensions between the local and global(Star and Ruhleder, 1996) and the long- and short-term occurs(Karasti, Baker and Millerand, 2010). For Star and Ruhleder, resolving tensions between the global and the local is through standardization and calibration. For Karasti et al., tension is resolved when the "here-and-now practices are afforded by temporally extended technology to be reliably usable everyday." Both scholars argue that standardization through conventions of practice and an installed base are vital in resolving the tensions. However, I take a different view, that though infrastructures and infrastructuring involve resolving these

tensions, it is much more and does much more than being a site where these two scales resolve. Could infrastructure exist without settling on conventions of practice? Could it exist outside the global/local or short-long term axis? Admittedly, the use of the term resolving tensions entails an implicit acknowledgment of scalability. In this sense, resolving tensions between scales entails making something scalable.

Away from infrastructures, scale and scalability issues are central to how many speak of the benefits the computer or digital provides. It is essential to think about the computer as the ultimate scalability device. The metaphors and language used by computer scientists and having practiced as one are evidence of this. For instance, the term “build once deploy everywhere/anywhere” or the more common “write once run everywhere” that speaks about the Java language’s cross-platform capabilities are telling examples. The selection of Java as one of the first object-oriented languages is also telling. Its cross-platform capability speaks to its scalability including in the material form. With the increasing role of the digital, systems thinking is the dominant mode of seeing and understanding the world. As stated by Murray, the computer was enabled by the two fundamental properties of hypertext and simulation(Murray, 1998). She argues that knowledge is created and linked from source to source through hypertext, a quality that did not exist before. In the case of simulation, she claims that through systems thinking, one could characterize the world in different ways and use the computer to simulate the world. She also mentions the need to see the world as an ecosystem, which is not different from how Edwards characterizes how the Earth is observed when performing

climate modeling. The planetary-scale represents an entire system, and planetary-scale climate modeling comes into play here.

Computability also comes with entanglements of scale. The internet and the computer as technologies are positioned as devices that help us escape the limits of time and space. The “annihilation of space and time” is the phrase used in describing technologies such as the railroads and telegraph that enable the exceeding of the time/space boundaries(Solnit, 2003). Thanks to the telegraph, futures markets in Chicago came to be, and thus space was collapsed. Incidentally, Edwards also highlights how the arrival of the telegraph in the mid-19th century made it possible for the first time to map the weather in large areas in almost real-time, as well as highlighting the first efforts to predict the weather based on the maps produced(Edwards, 2013). Harvey builds on Marx’s annihilation of space by time, showing how capital flows go beyond physical territories(Harvey, 1981). Time collapsed courtesy of technologies such as radio when mass media came to be, making it possible for people in different places to follow the same event through radio or television(Carey, 1992).

Due to this contextual collapse, working with the computer always entails matters of scalability. Technology’s romanticization as a tool that operates the same regardless of where and when one uses it was made prevalent. This ability to operate anywhere at any time is inherently attributable to some of the capabilities of the computer or computation. Bratton also makes a similar argument in his book the stack. He argues that computing systems are best understood as a global infrastructure that he calls a titular stack(Bratton,

2015). This planetary-scale stack is both a computational apparatus and a new geopolitical architecture. Though he makes an effort not to advocate for a new way to organize things, he presents seven layers that constitute this stack. Through his work, I argue that individual entities are subsumed into the hole, and thus the nuances of scalar effects are underplayed. However, another key takeaway, in my opinion, is on how the digital reterritorializes. The stack represents a new scalar framing away from the local/global dichotomy. Bratton's argument sits in contrast to Castells, who, when making a case for space of flows, rejects the notion of space being collapsed or as disappearing due to digital networks as he considers space as "the material support of time-sharing social practices(Castells, 2004)." This view, as mentioned earlier (the section on space and scale), has been criticized by scholars such as Marston for "flowsterism" (Marston, Jones and Woodward, 2005). For both, technology or the digital is scalable, allowing for time-sharing practices or as a global universal infrastructure.

Scalability, as commonly defined, can be a confusing term. The term seems to mean something that has the ability to use scale. However, as Tsing rightly notes, the term refers to expand — and expand and expand — without rethinking basic elements. For Tsing, scalability is a triumph of precision design, not just in computers but also in business, development, the "conquest" of nature, and more generally, world-making. She argues that scalability allows us to only see uniform blocks, ready for further expansion by discarding and dismissing the world's heterogeneity. This characterization results in the "precision-nesting" of scales where the small is encompassed neatly by the large only when both are well crafted for uniform expansion. Precision nesting abhors the effects of

transformation, meaning inputs are standardized and self-contained and unable to form relationships. This world-making and conceptualizing of the world are highly entangled. I argue that the self-containment present in systems thinking and computational thinking is due to computational abstraction, making computing an instrument for high scalability(Tsing, 2012).

Central to the notions of systems thinking, as championed by Murray, is the process of abstraction that tightly couples computability to abstraction. Through abstraction, the digital acquires scalability. As Coddington states(Coddington, 2015),

"Abstraction, the ability to break down information or problems beyond their immediate material context, is the central element of computational thinking. It is a cognitive process, rather than a practice necessarily done by computer; computing, then, is simply the automation of abstracted information and processes (Wing 2008). These automation processes often take the form of algorithms, which are occasionally considered a third element of computational thinking (Flew et al. 2012). Algorithms are the abstraction of a step-by-step procedure taking an input and producing an output to accomplish a defined outcome(Diakopoulos 2014a; Wing 2008). Algorithms can prioritize, classify, and filter information, and can be involved in journalism at several stages, including distribution—as in search results and audience metrics—determining topics to cover, or even writing stories themselves(Anderson 2013a; Carlson 2014)." (336)

As highlighted by Coddington, abstraction is the process by which immediate material contexts are represented in another form. Within a computational lens, abstraction is achieved through algorithms that entail the codifying of logic for inputs to produce an output. When computer experts speak about scalability in technical systems, there is an implicit understanding that a well-designed system should accommodate as many users and as many needs simultaneously. In a sense, a universalizing machine. In sum, a system designed to support ten people should easily support thousands without much effort in orchestrating computational resources. In practice, the divorce from databases and server-side languages has become more prominent where presently, middleware in the form of Application Programming Interfaces act as bridges allowing these two to connect. API's are a quintessential example of a technology that enables scalability and, in addition, are nothing more than computational logic packaged as middleware. Contextually, API's it could be argued, are sites where tensions between the server-side and the client-side are resolved. The creation of such computational blocks or logic blocks is part of what Tsing is referring to.

As abstraction is common in computing, so too are abstraction techniques in climate change modeling and computer-based knowledge infrastructures. Similar to the abstraction in computing, climate modeling takes on abstractions though of a different form. These abstractions codified through climate models enable the production of climate knowledge. Reno makes a similar point on the role of biological and Earth systems models that are abstract and global can be made concrete to non-specialists(Reno, 2018). A global/planetary infrastructure is required to enable

knowledge production in a changing climate and facilitates such modeling. As Edwards characterizes climate knowledge infrastructures, it becomes clear that there is a lack of an appropriate term to characterize or describe infrastructures that support environmental or sustainability values(Edwards, 2010). In retrospect, the term environmental infrastructures seem to portray such infrastructure accurately, though there is also the alternative that is ecological infrastructures where other conditions come into play. Some of these conditions are social, political, or cultural. These conditions make it difficult on how to characterize infrastructures that function as both technical assemblages and also as necessary tools for enforcing or preserving environmental values. The distinction I am trying to draw attention to may seem frivolous, but infrastructuring for an Anthropocenic age seems to demand much more politically, socially, and economically. The scale of the problem seems to be asking for more. The characterizing of such infrastructures as knowledge infrastructures obscures the scalar effects and implications, especially in dealing with an Anthropocenic age. On the other hand, information infrastructures also, as defined, seem to fall short. An information infrastructure is defined "as a global network of people, organizations, agencies, policies, processes and technologies systematically loosely coordinated to enhance the creation, production, dissemination, organization, storage, retrieval, and preservation of information and knowledge for people." The objective of information infrastructures is knowledge diffusion(Greer, Grover and Fowler, 2013). This objective brings me to the question, so what once we know?

Issues of naming and defining aside, Edward presents the challenge of downscaling in the context of planetary-scale infrastructures. He refers explicitly to climate knowledge infrastructures that were built to generate an understanding of the global climate system and points to their shortfalls, especially when one is required to "downscale" climate knowledge to meet the demands of the city, county, and state agencies as well as many non-profit organizations(Edwards, 2016). He states:

"*Downscaling means much more than producing higher-resolution climate data. It requires building technical, social, and institutional gateways that permit the transfer of knowledge – forecasts, causal theories, data, and interpretive or translational information – both to and from other knowledge infrastructures.*"

By downscaling, he is referring to the actual process through which the resolution of climate data is increased. Though he refers to the actual material process when dealing with data, it is not far-fetched to see how scale and scalability issues are present in this case. As I see it, downscaling provides another lens through which we could understand scale and scalability. Most of the discourse around scale and scaling has largely centered on moving from the local to the global, that is, scaling up. The term 'scaling up' speaks to the movement from the lower scale to a higher-order scale. The term scaling up within the computational sciences(partly) is almost synonymous with adding more technical resources. That means adding more servers, more memory, more disk space. However, scaling up also refers to optimizing systems to serve more users. Another view of scaling up is expanding local interventions. For instance, scholars such as Naber et al. argue for

upscaling local power grids as a sustainable solution in addressing climate change(Naber *et al.*, 2017). Other scholars highlight the need for scaling up the local or grassroots activities(Brown, Bødker and Höök, 2017; Lampinen, Rossitto and Franzén, 2019; Light and Miskelly, 2019).

The view is not any different within infrastructure studies. Ribes and Lee argue that "scaling up" is characterized in quantifiable ways such as increasing the number of collaborators, the quantity of data, the availability of computing cycles, or greater geographic reach(Ribes and Lee, 2010). Different scalar descriptors are employed in characterizing the properties above. For instance, large/small scale can describe how many collaborators are in a project. Big data versus small data describes the velocity, volume, and veracity of data(Kitchin, 2016). Borgman, however, uses the term, little data(Borgman, 2016). In referring to geographical reach, terms such as national, regional, or global are used in describing the scalar properties. Scaling can also be understood as moving from shorter to longer time scales, from smaller to larger geographical scales, and from the local to the global(Edwards *et al.*, 2007). Ribes and Finholt make a case for considering the scales of infrastructure that include enacting technology, the organization of work, and institutionalization(Ribes and Finholt, 2007).

Studying infrastructural scaling is complex as methods also have scalar entanglements. For instance, part of determining methods entails determining some form of scope or scale of study. For this reason, Ribes highlights how to perform an ethnography of scaling through scalar devices(Ribes, 2014). Unlike scaling up or scaling out,

downscaling has not received as much attention, especially in infrastructure studies. Does downscaling entail reducing the number of collaborators, the number of computing cycles, or the quantity of data, or in Tsing's context, reduce the uniform blocks or shrink rather than expand? This downscaling question is not an easy question to answer as conditions are remarkably different case by case. For instance, in climate change research, downscaling entails getting higher resolution data at higher frequencies, albeit in shorter temporal and spatial scales as perhaps opposed to global capital, where the dynamics are different. However, downscaling as a process could reveal more about scale and scaling. Here I draw upon the work of Jue, who argues that "sensing scales depends on the orientation of the subject and the layers of mediation and culture that enable the subject to observe the phenomena(Jue, 2017)." For her, scale is a matter of spatiality and one of phenomenology (the eyes we see through) and orientation (where we see from). Similar work that points to different orientations includes Scott's work on seeing like a state(Scott, 2008; Fourcade and Healy, 2015). Scholars such as Bratton fail in pointing out how planetary-scale computation, especially in the context of sovereignty, negotiates issues of agency from the whole to the individual. How does Bratton see planetary-scale computation agencies being downscaled to the User or the City? The positioning of the layers that he puts forth has some close linkages with how we may characterize different scales from the individual to the city scale or platform scales.

Tsing makes a case for non-scalability, arguing that scalability is a feature, while non-scalability refers to everything that is without a feature. For her, non-scalability attends to the work of contingency and failure and thus shows us scalability in action. The non-

scalability theory allows scales to arise from the relationships that inform particular projects, scenes, and events. Relationships are central to scale work, according to Tsing. Similarly, on efforts to "downscale" as highlighted by Edwards, Ehrenstein, et al. draw parallels on how scalability should be more usefully approached as a form of expansion that is attentive to possibilities of change(Ehrenstein and Neyland, 2018). These different notions on scalability bring to light how matters of scale affect, say, design practice and knowledge production.

Related to matters of scaling and downscaling is the discourse within STS on zoom. I think it is essential to highlight the pitfalls of zoom, especially when moving from one scale to another. One of the pitfalls I think that occurs, especially with geographers, is the thought of zoom and scale as one and the same thing. For human geographers, scale is seen as a hierarchical model of ascending scales, a nested model of ascending scales similar to Matryoshka dolls, or scales as forms of overlapping networks. This view assumes scale as hierarchical therefore to zoom is moving from one scale to the next and presupposes scale as inherently smoothly nested. Latour is also critical of this view as he makes a case for Anti-Zoom by invoking the work of Olafur Eliasson to make the point that thinking in terms of connections rather than hierarchy is preferred(Latour, 2017). Latour, in his essay, concludes:

"The Anthropocene has gradually eroded such distinctions. Thus, to fully comprehend the dimensions occupied by humans, or rather by all earthly creatures, it has become

necessary to devise new methodological principles: connectivity, yes; scale, no. This is the lesson in orientation I draw from the course in disorientation, provided by Eliasson."

However, I take a different view on zoom from Latour, taking a similar position to Horton and Tsing. Scale, especially in the context of the Anthropocene, is a concept that could help think through both the social and material conditions on how we got here. Horton explains, as mentioned earlier that the Anthropocene is a scale problem. Therefore, getting rid of scale as a concept may not help in coming to terms with what it means to be in this epoch. Zoom, I argue, is a mode of representation, a visualization mechanism that leads to this totalizing vision from the map maker. Does it do a great job communicating the intricacies involved in changing scale? No. The movie "powers of ten" is emblematic of scalar collapse, where how does one represent the various heterogeneous scales in one continuum(*Powers of Ten and the Relative Size of Things in the Universe | Eames Office*, 2013)? Do such scalar representations have to present a smooth continuum? Woods makes a similar point about the Powers of Ten films as he argues that it erases scale variance(Woods, 2017). As he states

"*Through movement from one scale to another, Powers uses two techniques to create its integrating effect: smooth zoom and a trope that I call scala, after the Latin root of scale. Smooth zoom is much discussed in criticism on the film. Taken up widely, from Philip Kaufman's Invasion of the Body Snatchers (1978) to the interface of Google Earth, it is by far Powers's most influential device. Yet smooth zoom is only one way of representing relations across scale, a method that inevitably reduces qualitative*

differences of scale to quantitative ones. Scale variance is the opposite of this reduction. Without scale variance, there would be no reason to mark differences between what ecologists call scale domains, since these would be understood by analogy with one another and collapsed into the scale invariance of which fractal geometry is one common example."

Horton argues that principally smooth scaling's central tenet is that our perception remains stable despite shifts in scale(Horton, 2017). That is, scalar shifts do not have different perception frames. Tsing, on the other hand, argues that the smooth zoom that is present in Google Earth is due to the property of scalability, primarily through the digital as the digital has the capacity to make the "tiny great and the great tiny." It is also due to this that the computer can produce precision nested scales(Tsing, 2012). Through scale variance, Woods goes further than providing criticism of smooth zoom to show the different scales of becoming. Other scholars, however, such as Schneider and Walsh, build on the anti-zoom argument by Latour making the argument of orienting climate downscaling visualizations as traces of connections(Schneider and Walsh, 2019). For them, the cinematic trope of "zooming" carries with it the political problems of synopticism and suggests a downscaling strategy of connectivity.

It is crucial to contextualize Latour's philosophical standing to understand his championing for connectivity. Latour's argument for connectivity is based on Actor-Network Theory (ANT). ANT's epistemological and ontological position essentially sees the world as nothing more than consisting of networks. In these networks, "actors" that

are both human and non-human act upon each other differently. The example Latour provides of a speed bump at a traffic stop explains how non-human objects act in the network(Latour, 2007). In the network, all actors are seen as flat, and thus this framing positions it as a flat ontology similar to site ontology and object-oriented ontologies. I have highlighted the criticisms of Latour's ANT framework, especially in the context of scale (view chapter on scale and geography). Marston argues against it because it is based on "flowsterism"(Marston, Jones and Woodward, 2005). I am also critical of ANT in the context of scale, not from a hierarchical position but from a perspective that assumes all actors to be equal and have the capabilities to act equally in a network. Even in the digital realm where the internet was championed as a great equalizer or say at the material level of a mesh network where all nodes are equal, hierarchies occur based on flows(*Inequality and the Internet*, 2015; Thompson, 2018).

In this section, I weave a narrative on the discourse around scale, scalability, and infrastructures. I also draw references from infrastructure studies to present how the discourse on scale has evolved within that realm. In particular, I make an explicit link between resolving tensions and scalability. To resolve those tensions means making something scalable. Through this thread, I demonstrate what scalability is by drawing on scholars such as Tsing and highlighting the concept of downscaling. It is due to scalability that I also expound on the literature on matters of zoom. I would like, however, to return to the discussion on abstraction, computation, and scalability. The question I present here is what about the computer that makes it an abstraction machine unmatched?

The perspective of seeing or characterizing phenomena as consisting of small uniform blocks, as highlighted by Tsing, is at the core of computation practice. Scalability in computation, unlike, say, modularity in plantations, is made possible through abstraction. From the temporal aspect (as highlighted in the temporal scale section), one could argue that what the computer has done is speeded up life. However, it is my view that the computer as a machine that is part of a wider digital infrastructure consists of several layers of abstractions. The abstractions differ from the representation of data as a set of zeros and ones to the development of logic gates, data structures, digital interfaces, algorithms and visualizations, and virtual machines. These, among many other abstractions, extended to make other abstractions makes scalability easy through the computer. Computational science tends to make such blocks as part of the build once, deploy everywhere paradigm. Metaphors such as packages, libraries, APIs, microservices, and containers are evidence of this tendency. Scholars such as Hanna and Park show how services such as containers are prominent due to the effort to be highly scalable(Hanna and Park, 2020). Part of the growth of different forms of computational abstraction is attributable to the development of object-oriented programming. Object-oriented programming is evidence of how computational forms enable the building of small uniform blocks. The declaration of objects, assigning them attributes and providing them with procedures to manipulate them facilitate reusability and scalability.

In the next chapter, I delve into my methodology. I begin by highlighting some methodological issues that I encountered in this project, especially when studying scale. I

then spend some time highlighting an ethnography of living with a weather station, which led me to my actual site that is the Sea Level Sensors Project. I conclude by discussing why doing an ethnography of scale is challenging as methods entail scalar conditions.

CHAPTER 3. METHODS

This methodology chapter has three main sections. The first section looks into grounded theory detailing the framework for data collection and analysis. In the second section, I interrogate scale as a factor methodologically and consider it in the context of studying infrastructures. I delve into the literature on scale and methods utilized in framing infrastructure as having scale. In the last section, I finalize with recommendations in analyzing infrastructures and scale and relating it to other work on infrastructures and scale.

Several scholars have grappled with the methodological quagmires of studying infrastructures necessitating new methods. The ethnographic study of infrastructures is complicated due to the turn towards the redefinition of the empirical aspect of infrastructuring. What exactly is the 'field' when studying infrastructures? Scholars such as Karasti et al. argue for studying infrastructures by acknowledging the ethnographer's role in constructing the field(Karasti and Blomberg, 2018). Building upon the discourse from anthropology that arose from debates on globalization as a complex and extended phenomenon, they demonstrate that researchers are active participants in constructing the field. From the ethnographer's perspective, the site is not merely bound to a place but rather an active inclusion and exclusion to demarcate an object of inquiry. This construction is essential to surface as studying spatial-temporally distributed phenomena needs a better definition of "the field."

To tackle this focus on the small- or micro-scale and redefinition of sites, other scholars have developed techniques that seek to make sense of how the field is constructed. Ribes presents “scalar devices” as a useful technique in doing ethnography that does not lead the ethnographer to define boundaries for the site but instead rely on how infrastructure is scaled(Ribes, 2014). Others such as Pollock and Williams argue for the Biography of Artifacts and Practices approach where site selection is strategic and provisional(Pollock and Williams, 2012). In the context of scale and scaling, other methods have been put forth as tools in understanding infrastructuring. Methods such as multi-sited ethnography or fractal analysis illustrate a form of scalar working that entails scaling up or downscaling what is considered the site(Jensen, 2007; Fortun, 2016).

I argue that constructing the field is an active scale defining process. Be it the multiplication of sites or defining what is included and excluded in constructing the site. The construction of the site and delineation of the object under inquiry is scalar in character. Site or field construction entails scalar workings. It is essential to acknowledge how the construction of the field is also constructing scale. Thus, we need to be cognizant of how scalar constructions affect research outcomes. However, studying manifestations of globalization is challenging, especially ethnographically. Challenging in that ethnographic practice mostly deals with specifics and particulars at specific sites. Malinowski’s work in the Trobriand Islands through the practitioner’s immersion onto the site is an example(Malinowski, 1922). The challenge of the micro being used to explain the macro is not as straightforward. Therefore, as infrastructures do much more than link the global to the local, ethnographic practice needs to be well-grounded.

Furthermore, this is also a scalability issue, as argued by Tsing when contextualizing the application of scientific frameworks onto other scales(Tsing, 2012).

In this dissertation, I study the SS project using grounded theory. To learn the intricacies of scale in the SS project, I utilized grounded theory as it provides an excellent mechanism for inductive reasoning. Grounded theory is a qualitative method that entails a deep interplay of both theoretical generation and the conduction of the research. The direct observation of a phenomenon under study is used in theoretical generation. Data collection practices are also part of the construction of the field, which is inherently a scale question. As data collected is used in the theoretical generation, rather than, say, hypotheticals testing, the demarcation of data collection procedures consists of defining scale. I will go into detail on this aspect in the grounded theory subsection.

As I was also a participant in this project, I highlight how my role enabled me to construct the field and how this affected my method. Initially, my entry to this site was as a GIS developer. This role changed as aspects of scaling came into play. My role shifted from being a developer to one of a social scientist, thus repositioning my relationship with the project. As a researcher, I had to navigate from being close to the object of study as an active participant to further distancing myself from the project. During my fourteen-month interaction with project participants, I got the chance to check in with them some of my findings or cross-check items from one interview with another. Being physically present also helped immensely. In these circumstances, grounded theory does well where

the ability to engage with the participants during the period study continually provides for more opportunities for revelations and different understandings.

In the next section, I spend time highlighting grounded theory and how I employed grounded theory as an instrument for understanding scale and scaling in infrastructures.

3.1 Grounded Theory

As mentioned earlier, grounded theory is more of an approach. However, as part of constructing the site, it is essential to highlight how it molds data collection and analytical techniques as a method. This section provides how grounded theory played a role in molding my theoretical generation, data collection practices, and analytical frames. Grounded theory is a widely accepted research method put forth by Glaser and Strauss(Glaser and Strauss, 1967). In their framing, grounded theory pieces together the work of theorizing based on data. Since their seminal work on grounded theory was published, other authors have developed different strands of grounded theory. The Pragmatist philosophical tradition influenced its development(Bacon, 2012; Charmaz, 2014).

Glaser and Strauss's framing of grounded theory(GT) is what is considered classical GT(Glaser and Strauss, 1967). In this frame, data collection practices are not procedural and detailed guides on collecting data are nonexistent. This is a major critique that Clark, another prominent grounded theorist, makes about GT. The loose and guideless data collection in this form of GT. Importantly, they introduced the transactional nature of the

site or the field as the center of collection and analysis. That is tracing transactions and actions of different actors on the site. Strauss and Corbin developed a strand of GT that seeks to bring about objectivism and reflexivity(Corbin and Strauss, 2015). In this strand, they argue that researchers need to be reflexive of their role. By bringing in objectivism, they argue that researchers can discover and reveal objective realities. This turn towards objectivism intractably links to theorizing, especially in the social sciences. Another thread developed out of GT is Charmaz's constructivist framing(Charmaz, 2014). For Charmaz, she foregrounds the researcher's role in constructing theory and collecting the data. This position means that the researcher's role is interpretive more than a form of reporting. The latest thread of GT was by Clarke, who emphasized situational analysis and the interactions in a social arena(Clarke, 2003, 2005). The prominent position put forth by Clark is that the conditions in which a situation occurs should also be under study. The development of situational maps is part of the data collection process. This dissertation, in my assessment, tends to take more of Charmaz's position.

In GT, data collection has primarily centered on observation and interviews, which are inherently ethnographic techniques. Though scholars have highlighted the loosely defined nature of GT as a method, one could consider them ethnographic(Timonen, Foley and Conlon, 2018). The blending of GT and ethnography has provided for an orientation towards theoretical generation, unlike traditional ethnography. Scholars advocating for this hybrid approach have utilized phrases such as 'grounded ethnography'(Battersby, 1981) or 'grounded theory ethnography'(Charmaz, 2014). In this dissertation, I use grounded theory with multi-sited ethnography to study the SS project. I utilize these two

as both are methods with a focus on comparability, essential when we think about scale and scaling. The field as defined by both is also contingent and unstable. I argue that, especially when thinking about scale, both help explore how we navigate scales. Also, in the discourse about the global and the local, this comparability is helpful and reorients us away from dichotomies. I will detail more on multi-sited ethnography in the following subsections.

Grounded theory practice has recently pivoted into recognizing that theoretical formulations do not begin on a blank canvas. Earlier scholars of grounded theory made a case for entering the field without preconceptions. Among other grounded theorists, Clarke argued for investigators to be "theoretically sensitized" accessing the site with some knowledge on histories, some questions, or some areas of interest(Clarke, 2005). As an ethnographer accessing the SS site, I carried with me quite some knowledge of the project. To contextualize this knowledge, I introduce some of the work I had done earlier that prepared me to access this site.

3.1.1 Ethnography of Living with a Weather Station

As a doctoral student working on environmental sensing research, I started a research project studying citizen weather observers in 2018. I had read Paul Edward's "A Vast Machine," which goes in-depth into the knowledge infrastructure that exists, enabling scientists to understand climate change(Edwards, 2010). In his piece, part of this infrastructure he details is the work of local citizen observers who collect data and submit it to the National Weather Service (NWS). As someone with some technical skills, I wanted to be a citizen observer collecting data as many other citizen observers and joined

several online forums where local citizen observers share tips, ideas, and resources. Other than following weather forums such as WxForum.net, WeatherWatch, Weather Underground, among many others, I purchased a weather station to be an active participant in this community. This was my introduction to the 'field.'

To this day, I still operate the weather station despite the challenges of dealing with this dissertation and a change in my site, leaving it on my balcony unattended just collecting data. However, before then, over a period of six months, I set up the weather station and set up a house scale infrastructure for weather monitoring. After setting it up, I took notes highlighting what it meant to live with a weather station every week. Over the six months, I learned a lot about sensing and DIY hacking. Though I was already familiar with custom and DIY electronics, navigating such a unique discipline was interesting. For instance, the weather station comes with a display allowing one to see the sensors' readings. The apparatus requires installation in a place not close to the building as walls bring about temperature inconsistencies and not underneath or close to a tree. Tree cover also results in inconsistent readings, thus positioning it away from any tree canopies. The station also has a solar panel for measuring UV radiation that is also a critical reading useful in weather forecasting.

As more time passed, I made other adjustments to my setup. As the display also works as the site where data is collected and sent to external websites, the display's disk drive would get full in two months. I connected a Raspberry Pi (a microcomputer for hardware hacking) to my display, allowing for the data collected to sit in a database in my network.

This adjustment reduced the number of times I had to flush the data stored in the display disk drive. This extension also allowed for more functionality, such as a custom web service where I could visualize the data via a custom web page rather than the pixelated liquid crystal display. Being able to see charts on an interactive webpage in my home network was interesting. The same custom open-source package useful in plotting my data also came in handy as it enabled me to contribute my data to other external entities(websites). In this case, I would submit my data to NOAA's citizen weather observer program, sites such as WeatherUnderground, Windy.com, among others. The custom script, better known as a 'cron' job in computational terms, would run on the hour, sending my data to external sites helping them improve their forecasts. Data sent to such services contribute to improving forecasts and commoditized, resold, and repurposed in some cases. However, these sites also act as spaces where data backups occur. The syncing of data between the home and such services is a form of scaling due to the relaying of data to an infinite data store that seemingly never runs out, unlike at home. Unlike my Raspberry Pi, the external data store is seen as limitless, with capabilities to handle extra load and data.

Sending data out to other entities also reveals the multiple scalar workings of the weather observation process. Sites such as the Citizen Weather Observers Program (CWOP) and Weather Underground would occasionally send alerts if my data needed re-calibration. I occasionally carried out re-calibration as it meant that there were errors in some of my readings that needed to be checked and rectified. Hulme refers to this as keeping the register, highlighting the work of maintaining the integrity of

datasets(Hulme, 2011). I would then delete any erroneous data after checking what was wrong. In one case, the rain gauge registered faulty readings, which came to my attention due to an alert from the CWOP service. It had rained that morning and on checking the graph plotted on the web service, significantly higher readings were registered. The graph also had erratic readings with significant deltas. Due to the alert, I checked the rain gauge to discover that the gauge had some leaves inside and some bird droppings as I had not cleaned the gauge in a while. It is because of the data collected by other observers around me that such alerts could be issued. The scale of data collection around me to rectify my sensing instrument.

In another case, a power surge in my apartment block had resulted in a non-graceful shutdown of my Raspberry Pi. On repowering the device, the time and date update fetched from Network Time Protocol (NTP) servers failed, resulting in some data collection with wrong timestamps. The timestamps showed the first of January 1980, yet it was neither January nor 1980. The date was also wrong. To remedy this problem, I added a Real-Time Clock (RTC) as a hardware module capable of handling such events. The addition of the RTC also meant that every time I powered up the Pi, I would not have to wait for the network connection to pick up. As a hardware module, the RTC clock manifests scalability. The structure of open-source hardware has also moved to the material form. Like the plantations that Tsing highlights as evidence of scalability through modularization, hardware modules are also a testament to this(Tsing, 2012). Adding a small function such as a temporal register is simple: buying a module and adding it to the circuit through a General-Purpose Input Output (GPIO) port.

Carrying out this autoethnographic work enabled me to be reflexive of the process of sensing at the home scale. In the context of scale, my homestead was a scalar boundary. However, despite my domestication of the station, my activities with this device entailed working across scales. In one form, through calibration, a larger geographical scale is essential in resolving moments of infrastructural breakdown at home. In another form, my data is used for more precise forecasts. This precision is what Tsing argues is a product of scalability. Another form is in the idea of bigdata in manifesting the scale of data collection. By sharing my data with different platforms, I contribute to a definition of scale through data. In addition, as part of the knowledge infrastructure that Edward's christened "A Vast Machine," data collection at this scale plays a vital role at a larger scale in climate change knowledge production.

In addition to doing an autoethnography, I got the chance to interview seven citizen weather observers and a designer working at Weather Underground. These interviews were illuminating as participants revealed why they collect the data and share it with different platforms. Designing services based on crowd-sourced data is part of working across scales for the designer. The process of providing information to digital services on the mobile phone-based on data collected across a larger geographic scale is a testament to the scalar workings at play. In one sense, the product cannot work without the input of citizen weather observers. In addition, using open data collected by institutions such as NWS and NOAA also form part of designing such services. Actually, private forecasting industries rely most on government data for their needs. For weather observers, most

mentioned coming to be involved in weather observation out of personal interests in technology or their occupation as farmers. There is a large segment of weather observers who are active participants in the ham radio community. Others come to the practice as farmers or as participants located in areas that receive very poor forecasts. For them, installing a station and sharing the data plugs the information gap.

What does the previous work on weather observation say about my study on the Smart Sea Level Sensor project? One thread was the element of scale, as mentioned before. At the domestic level is the work of maintaining the data weather observers have to do. My problems with the temporal aspects of data collection also helped reveal the temporal infrastructure that powers the modern Internet. Through this breakdown, I was able to make visible the use of time servers and learn how time servers are maintained by institutions such as the National Institute of Standards and Technology using custom hardware that is in sync with GPS satellites orbiting in space. Similarly, it is the role that national agencies play in data collection that allows private entities to capitalize on the open data shared. The scales in play here are remarkably different.

My experience with weather observation enabled me to think through scale. However, as the homestead scale was the site where this autoethnography occurred, there was an interest in exploring how an ethnography at other scales could reveal. This is what led me to the SS project as it entailed building an infrastructure. It offered a better opportunity as I could follow the infrastructural development process more in-depth. It is not that infrastructural development does not occur in citizen weather observation, but rather

questions of access puzzled me in this process. I now turn to highlight how I utilized ethnography for this dissertation.

3.2 Multi-sited Ethnography of Scale

In my dissertation, I employ multi-sited ethnography as it is central to the debate on scale. George Marcus, operating from the anthropological tradition, introduced multi-sited ethnography as a method(Marcus, 1995). He argued for a move away from defined single sites as the demarcation or object of study towards multiple observation and participation sites. He argues that multi-sited ethnography helps move away from dichotomies such as the local versus the global. I also specifically use this methodology in infrastructure studies as several scholars claim that infrastructures link the global and the local(Star and Ruhleder, 1996; Edwards *et al.*, 2007; Karasti and Blomberg, 2018). As the SS site is also an infrastructure, demarcating one site as the only site would exclude essential parts of that infrastructure out of the site. Moreover, in contextualizing the importance of multi-sited ethnography, Marcus states:

"In anthropological work within the field of cultural studies of science and technology, the tendency toward multi-sited research is most prevalent in the following topical areas: the study of issues concerning reproduction and reproductive technologies (originating in an important domain of feminist research in medical anthropology) (38); epidemiological studies in medical anthropology (4a); studies of new modes of electronic communication such as the Internet (see e.g. 19, 61); and studies concerned with environmentalism and toxic disasters (e.g. 54, 88, 102). Another area is the study of the

emergence of biotechnology and "big" science projects like the human genome project [of particular interest here is Rabinow's (76) work on the discovery and commodification of the polymerase chain reaction, especially related to the multi-sited style of his earlier work on French modernity (75)](Marcus, 1995)"

Multi-sited ethnography is suitable for the SS project as it is environmental in focus and entails building a digital infrastructure. Marcus argues that multi-sited ethnography in STS has pushed away from the direction beyond lab studies towards complex spatial and temporal spaces(Marcus, 1995). Complex fields such as environmental humanities and STS would benefit from this kind of ethnography. This move has built upon the work of Haraway in the cyborg manifesto that presents several sites that constitute an object(Haraway, 2006) or Latour's detailed work on the production of science(Latour, 1987). Using Marcus' 'tracking' approach that includes following people, things, metaphors, stories, biographies, and conflict across sites enables one to carry out a multi-sited ethnography where the field is contingent and unstable. As mentioned earlier, GT is also useful in dealing with contingencies and instability. An example of how I used this methodological approach was asking for inscriptions, texts, and references to metaphors of scale. Phrases such as "this is not scalable," "build once deploy everywhere," "we need to scale up," or even the term "coverage" bring out attention to the contingency of how the field is defined. In this form, the definition of the site determines the scale. In a sense, different sites represent different scales. Through this understanding, infrastructure is seen as emergent and unstable as it is continually developing and being maintained(Bowker and Star, 2000).

In the next subsection, I highlight how I employed grounded theory and multi-sited ethnography to study the SS project.

3.2.1 Smart Sensors Project

My entry into the SS project was not as straightforward. My advisor had previously interacted with Dr. Davis, a project lead of the SS project. He pointed me to the project as he was aware of the challenges of not having a physical site to do ethnographic work. The challenge with the weather observation study was that weather observers are scattered all over the globe. Thus, doing a well-situated ethnographic study seemed methodologically problematic. I found it challenging to find micro-communities of the weather observers situated in spatially demarcated places. As mentioned earlier, qualitative ethnographic methods are laser-focused on the micro. A site well defined is essential in carrying out this kind of work. I worked to find weather observer clusters who, perhaps due to their location, practice observation uniquely. Though I did find a couple, issues of access to the site arose. Part of resolving this issue of access was also becoming a weather observer.

Moreover, sensing the home environment has different affordances from sensing through larger-scale infrastructural developments. Though I did get to use critical making in environmental sensing at the home scale, embedding myself to a site such as the SS project provided more opportunities to study infrastructural development from different perspectives. For instance, issues such as funding and custom modeling are striking

examples of how the home scale differs from the SS project scale. At the home scale, all I needed to do was ask my advisor for approximately 150 dollars from his faculty fund. Very much unlike the SS project that entails doing much more tactically on the funding front. Essentially, it is also important to acknowledge how this is part of constructing the field. In one frame, issues of accessibility play a role in constructing the field. In another, is the suitability of the site. Additionally, my experience in the study of weather observers also prepared me to move onto the SS project. I was not joining the SS project on a 'blank slate.'

As a site, the sea level sensor project is in Dosta, Ventria, an area at risk of sea-level rise. The project's use of custom Do-It-Yourself (DIY) sensing kits stood out, given the relation to my weather observation study. At that moment, moving from the weather observation study to the smart sea level sensor project seemed promising due to the different scales at play. Unlike weather observation occurring at the domestic scale, the SS project seemed to have multiple scalar intricacies. The political scales, the temporal scales due to long-term scales such as climate change, or the geographical scale intricacies made this site ideal. Besides, the team's composition across different disciplines with different operational scales was also unique, leading me to reach out to the project as my site. As many of the project participants are from UoD, this made it easy to make connections.

To join the smart sea level sensor project as my potential site, I sent out an email to Dr. Smith. I introduced myself and asked if I could have the project as my research site.

After some weeks, I decided to take the initiative and applied to a WebGIS developer internship posted on the project website. My experience made it ideal for applying for this position. I had worked as a GIS developer at a leading university in the North East of the United States. My work then entailed building big data geospatial pipelines for researchers across the university and externally. This entailed building systems that crawl geospatial data and metadata standards and ingest them for researchers to query through a simple interface. A kind of search engine for public and some private geospatial data. Before then, I had worked at East and Central Africa's largest media company, building data infrastructures for storytelling, including maps utilized in election coverage. As this is something I know pretty well and have quite some experience in, I applied for the internship. The internship seemed oriented towards hiring an undergraduate. However, I put that to the side and went ahead to apply.

I got to meet Dr. Davis and Dr. Smith in their office a few weeks after. In this meeting, they interviewed me and informed me that I would be joining the project that summer as an intern working on software development. My introduction to this project's custodians was through an internship, as my efforts to access the site via email initially bore no fruits. They mentioned that they were not expecting a doctorate student with extensive experience to apply for the position as they were specifically looking for an undergraduate computer science student. Luckily for me, it was late in the term when most undergraduates already had found internships providing me with an easy opportunity to join the project. The temporal rhythms and routines aligned to my benefit necessary when constructing the field.

For the first three months of my time in this project, I was part of the team working on the dashboard. The dashboard team already had participants though tensions surfaced over what I could contribute to the project. In reflection, I attribute this to scaling entanglements. Unlike in computers, where adding a new memory chip or another server could be trivial, adding a human to a project group is not easy. Humans are unlike modules despite the success of Fordism. Scaling human infrastructure presents different conditions from scaling an information infrastructure. Because I had no funding that summer, participating in the sea level sensor project was a mechanism to sustain myself and be embedded as a researcher. In doing ethnography and partly working on the dashboard, I grappled with positionality issues for a while.

However, as the process of developing the dashboard took longer, I could not get much done as the development could not start without first doing design research. There was no sufficient work for me at this stage as the team focused on doing design research taking close to three months. Temporalities were out of sync. Though design research has become a commonplace term and amorphous, in the context of the SS project, it refers to the process of carrying out research to find needs or problems and involves the explorations of possible interventions(Faste and Faste, 2012; Giaccardi *et al.*, 2016). In the case of developing the dashboard, this entails studying Oliver's (one of the participants) daily routines of how he keeps track of emergencies and flooding across the county and what interventions would make some of these routines easier. I was involved

in meetings during the design of the dashboard and utilized those opportunities to ask Oliver and other team members questions.

As highlighted in the reorganizations of roles, the changes in temporal scales at which different people operate may not be smooth. Unlike adding extra memory, adding a human to a team entails several complexities. One example is the reorganization of roles to determine who does what based on experience and interest. At times having an alignment in project goals and personal interests fosters participation. It takes effort to resolve tensions and align interests. After two months of not contributing substantially to software development, I tactically took a back seat as an observer reframing my participation in this project not as another active participant but taking on a role further removed. Methodologically speaking, this may have been better and ideal as it is what I tried to get in the beginning. From an active participant, I took on the role of an ethnographer.

However, it is important to highlight that in no way am I saying that there is anything wrong with ethnographers who are also active participants. Marcus, in his positioning of multi-sited ethnography, argues for the ethnographer as a circumstantial activist. He argues that the movement across sites entails specific and circumstantial activism formed by the conditions of doing multi-sited research. As an ethnographer-activist, one has to deal with cross-cutting, and at times, contradictory personal commitments, and resolving such issues is by renegotiating identities in the different sites. In my case, this form of activism entailed joining the project as a developer and taking on an ethnographer's

identity later on. Since joining the project, I carried out participant observation, recorded detailed memos and field notes, and carried out semi-structured interviews. In the next section, I detail how I carried out each of these in detail.

3.2.2 Participant Observation

For more than a year, I embedded myself in the project attending the bi-weekly meetings online, workshops at different sites, and visiting participants at different sites. As I was also part of the dashboard team, I attended several meetings to tease out the dashboard design. Part of this was also observing how Oliver, West's County emergency manager, uses different digital tools and data from the Fort Norad tide gauge to make sense of flooding across the county. I remember being taken through by Dr. Brian and the rest of the team on how to build a custom model. Sitting at home over an online call going through the steps in creating the custom regional model revealed the role of scale in that process. In both of these incidents, observation entailed following in the discussions and following routines through a screen share. At the end of the bi-weekly meeting, I also took notes, noting down unique anecdotes from participants. Occasionally other collaborators would drop in to talk about their work and project updates in general.

However, workshops were distinctly unique sites as I was able to write more detailed notes, given all participants were mostly in the same room. Co-location provided different affordances from co-presence(Beaulieu, 2010). Since joining the SS project, I have attended three workshops in total, all occurring in different sites within the county. The first workshop I attended occurred at the old city hall. The second at the city campus

of the UoD, and the last one occurred at a local school library. In these workshops, I would follow the proceedings taking notes, and earlier on was involved in some of the breakout groups. The hosting of workshops was intentional as these are sites that make up my site, all contribute differently to the project.

Unlike bi-weekly meetings, what the workshops also enabled was the ability to meet local participants and institutions easily. Because most of the project team was at the workshops, the team would organize meetings with local political leaders, residents, partners, and potential partners to promote the project. It is because of such meetings, for instance, that I was able to be in the room when the project would make presentations to the city manager and other elected officials. Also, I was able to attend meetings with county leadership taking detailed notes. I always took a distant position in these meetings, never sitting on chairs next to the table. I sat silently following presentations and deliberations seated at the furthest corner. The only occasions I spoke were during introductions, which became almost mechanical, stating my name, mentioning that I am a student, and ending it at that.

I also attended outreach meetings where residents attended. For example, one of the first meetings I attended was after the first workshop, where the project team had an opportunity to talk to residents. This meeting occurred at a local museum with a large auditorium where residents were sensitized about the project. Also, in the last workshop held at a local school library, we attended the school's staff meeting with members of the project team. It was an opportunity to learn about the dynamics at a school and how the

project team leaders engage with such diverse audiences. As Marcus states, following metaphors and language across different audiences is one way of doing multi-sited ethnography(Marcus, 1995).

It is important to emphasize that I support Beaulieu's position on co-presence as part of constructing the field site. Traditional ethnographic practice broadly frames accessing the site through the lens of physical co-location. That is, for a proper ethnographic enterprise, a physical location well-demarcated is desirable. Co-presence' decentralizes the notion of space but does not exclude it(Beaulieu, 2010).' This means that co-location is part of co-presence and does not assume an availability to interact when in the same space. More importantly, though, co-presence enables us to account for other modes other than physical co-location. This consideration of other modes is part of constructing the field and highlights why multi-sited ethnography is ideal. For instance, phone calls or bi-weekly calls are examples of an establishment of co-presence without physical co-location.

I remember how I interviewed Dr. Brian over an online video conferencing call. My advisor and I thought we were to meet in his office at the university. While waiting for him outside his office, we learned that he was not around on campus. We eventually were able to connect through the call. We found an empty space in the university building to do our call. He was at home and very apologetic as he thought he had reached out to me to meet online. However, at the beginning of the call, what was instructive to us was when he mentioned that he was in quarantine at home as the Coronavirus infected

someone he was in contact with at a conference. This was in late February before the institution of lockdowns by different government agencies. At the time, we did not think much of it. We continued with the interview. Being at home meant the site and conditions at the site play a role in the construction of the field. During the call, his daughters walked in, and he paused to give them instructions asking them to check with their mother.

In such online calls, similar moments stick out. As part of an ethnographer's work, it entails deciding what to exclude and what to include in these discussions mediated through other modes. However, such interactions also help in forming an identity of our participants when observing them. I now turn to detail how memos and fieldnotes were part of my grounded theory and ethnography.

3.2.3 Memos/fieldnotes

During my study, I took several memos and fieldnotes. I mostly jotted down fieldnotes after specific events, and in some cases, my fieldnotes detailed design research issues that surfaced given my earlier role in the project. However, most of my fieldnotes came from attending the different events or even after having casual conversations with team members. After the workshops and meetings, I would quickly rush back to the hotel room to take more detailed notes. This notetaking involved filling in gaps for things that I may have missed. In some cases, as I couldn't keep up with the pace of the discourse in the meetings, I would leave pointers that would act as guides enabling me to make revisions later on.

I also wrote memos detailing aspects of specific interactions that stood out to me. For instance, based on a conversation over lunch with some project members, tensions present between different geographical scales of governance surfaced, and the historical context revealed. This tension is perhaps not surfaced explicitly in interviews; however, additional context arises from a casual conversation. Memos provide good opportunities for theorizing. They also provide an opportunity to shape the questions to be asked in the interviews. For instance, due to writing memos and my experience as part of the dashboard team, I considered what it means to downscale and infrastructure. Another example is a memo that I explored that looked into STS and the practice of measuring and establishing measurements. One aspect I hope to pick up in the future is measurements and measuring as infrastructure. Memoing is part of grounded theory and allows for theoretical explorations that in part also constitute constructing the field. Part of my theoretical exploration also entailed writing rough ideas on index cards and making linkages between the evidence and other academic literature.

3.2.4 Interviews

For this dissertation, I carried out several interviews with different project participants. I developed a semi-structured questionnaire, which I utilized as a guide when interviewing. Most of the interviews happened in February and March of 2020, a few weeks before mandated lockdowns came into effect due to the Coronavirus epidemic. I interviewed fourteen participants, out of which interviews with two occurred through online teleconferencing tools. Of the two, one was held remotely due to the lockdown enforcement while the other participant was quarantining. The one in quarantine had

come into contact with someone with Covid-19 at a conference. This was in late February, and lockdowns at this point were not yet in effect.

University was still in session, and it was the first case where someone I knew had been directly affected. The other interviews were done by meeting different participants at different sites. I spend close to three days in the city visiting project members interviewing them. As part of constructing the field, I interviewed project members who had engaged with the project for more than six months. Though, earlier on, I did not have a six-month limit as part of constructing the field. A result of this exclusion was some interns involved in the project in the summer of 2019 were not interviewed. I was not sure their short duration of fewer than two months with the project would reveal much. Some participants, part of the city and county infrastructure, were interviewed as part of the dashboard development process. For instance, I got to interview the public works surveyor in May 2019. I also held several interviews with Oliver at this stage before having a more general in-person interview in February after our workshop.

A total of 14 interviews with project participants were done, spaced out to allow me to process and think through other aspects I could surface in the next interview. During the February workshop, I interviewed all the participants based in the city and the county over three days. I visited participants in their sites of operation. For instance, I interviewed Oliver in his county emergency office. I interviewed Ethan in the HH offices. Being able to do interviews in these sites also allows for a different form of participant observation. It also helps contextualize the different sites. For instance, my visit to

Oliver's office where several television sets tuned to different local news outlets played in the background muted, or the hand radio's presence on the table revealed more about his work. I did more interviews in March and finalized the last interview in the summer of 2020 via digital tools due to the pandemic. Those interviewed in March were mostly participants from the UoD stationed in Dublin. Interviews took approximately 45 to 60 minutes and were recorded.

In my interviews with participants, one of the questions I asked participants was to identify scalar breakdowns. I would specifically ask participants at what time they recognized they were operating at the wrong scale. This question builds on the notion of fix where operations change, or scale breakdowns occur when translating to other scales. For instance, the example elaborated in the spatial scale section (next chapter) on scaling up using lift stations rather than libraries highlights the contingencies when changing scale. Besides, this line of questioning also allows for participants to define what scale they operate in. Through interviews, participants revealed different ways of defining scale. For instance, one participant spoke about the research scale while another defined their work done in the context of the neighborhood scale. In the context of multi-sited ethnography, scholars such as Fortun have illustrated how scale could be presented as different sites(Fortun, 2016). Fortun develops different sites based on scalar operations. As one of the sites, she characterizes the macro scale as the site where markets, laws, and other trans-local institutions work. Another site she describes as the mesoscale represents where social organizations and their interactions carry out activities. Similarly, I extend

this to explore how scalar constructions also take the form of sites of ethnographic enquiry.

To analyze the data, I had the audio files converted into text by a popular transcription service. As I received a new transcription, I would load it into the NVivo software and open code it. As part of my grounded theory process, I began with no predetermined codes analyzing text and ascribing codes that would come to mind. For instance, I would code text in relation to the concept of space, the notion of temporality, or the notion of scale. This coding also involved looking at the language used, the metaphors, and things in relation to different concepts of scale. After a round of open coding, I organized the codes and specifically focused on aspects of temporality, space, scaling, and downscaling. For instance, in the closed coding, I looked for time references such as clock-time, relational time, and other forms in the case of temporality.

3.3 Methodological Quagmires

When beginning this study, I grappled with the question of how do I use a non-anthropocentric method? I have detailed in the literature review the pitfalls of anthropocentrism. This question is prevalent, mainly as the sea level sensor project entails other non-human actors. How does one do an ethnography that is not human-centered as non-human actors such as the moon, the earth, the sun, the sea, or the ocean take significant roles in my site? As mentioned earlier, ethnography is a human-centered practice, thus failing to take into account non-humans though they are part of our world. A divide between nature and social science is resultant due to this methodological

approach that is anthropocentric. To better address climate change issues and the current Anthropocenic age, non-humans need to be factored in and incorporated. As the definition of the Anthropocene also centers on man, further context is needed to cross the divide between nature and society. Scholars such as Latour have put forward actor-network theory as a mechanism that could decenter the man(Latour, 2007). Others have introduced discourse on multi-species ethnography, making a case for ethnographic perspectives that account for animal and plant species(Kirksey and Helmreich, 2010). Other approaches such as thing ethnography have advanced as methodologies that decenter humans within human-computer interaction(Giaccardi *et al.*, 2016).

This methodological quagmire, on my part, also deals with questions of scale. As mentioned by Oran Young, writing from an environmental humanities perspective, social scientists discard scale(Young, 1994). Young argues for the reintroduction of scale within social sciences, mainly as scientists usually deal with entanglements of scale. As Latour also states in highlighting the problems of scale that social scientists wrangle with: "*We use a model of analysis that respects the boundary between the micro- and the macroscale, between inside and outside, that sciences are designed to not respect*"(Latour, 1983). He argues that this problem results in a divergence in methods and scholarship where qualitative research covers microspheres while quantitative covers more significant territory. For Latour, Actor-Network Theory allows for a methodology and analytical framework to understand scale as a product of actors. As Ribes argues by building on Latour's point, "the Laboratory is not a site for micro activity but rather a locale for mediating scale"(Ribes, 2006). It upon this foundation that Ribes puts forth a

methodological approach of doing an ethnography of scaling(Ribes, 2014). Grounded theory and multi-sited ethnography, I argue, are useful in helping us understand the construction of scale. More importantly, it reveals to us how or what scaling is when traversing different constructions of scale. Scale and scaling are intractably linked.

I finalize by highlighting infrastructural inversion as a methodology. Infrastructure inversion is another methodological approach introduced by Bowker and Star to bring to light the invisible nature of infrastructures. Through infrastructural inversion, the foregrounding of the parts that operate in the background happens(Bowker and Star, 2000). For instance, the human infrastructure involved in repair and maintenance is an example of infrastructure that is sunken. As highlighted by Karasti and Blomberg, inversion brings attention to the mundane and focuses on materiality(Karasti and Blomberg, 2018). The place of technical specifications, tasks considered boring, and other elements considered mundane play a role in defining the field. Infrastructural breakdowns are unique moments that make the invisible visible. For instance, during one of the workshops, the power supply breakdown and the power backup system's failure at the university's server cluster revealed its location to participants unaware of where all the data is stored. The loss of power and the breakdown of the backup infrastructure revealed the changing nature of the site as actively constructed. In this case, the power system at Dublin and UoD's backup power systems come into sharp focus.

In the next chapters, I detail my findings centered around three core ideas. One is the role of spatial embeddedness in scaling. The second is an exploration of what scaling is along the temporal dimension, and lastly, I focus on how to scale a human infrastructure.

CHAPTER 4. SPATIAL EMBEDDING

Several scholars within infrastructure studies and Computer Supported Collaborative Work (CSCW) have highlighted the role of spatial scale in infrastructures. Commonly, based on the work of Star and Ruhleder, spatial scale characterizes the reach and scope of infrastructures(Star and Ruhleder, 1996). For them, an infrastructure comes about when it reaches beyond a single site practice on a spatial scale. They also maintain that when tensions between the local and the global are resolved, an infrastructure occurs. Other scholars such as Edwards et al. highlight the need to study infrastructure's layered nature and how it navigates across scales(Edwards *et al.*, 2007). In this section, I begin with the manifestation of spatial scales in the SS project. I seek to move beyond the global versus local dichotomy to demonstrate how infrastructures navigate disparate spatial scales.

The discourse around spatial reach and scope of infrastructures has mostly focused on different threads. Scholars such as Karasti and Ribes have focused on the methodological quagmire of how to study infrastructures(Ribes, 2014; Karasti and Blomberg, 2018). Ribes makes a case for scalar devices as a mechanism to perform an ethnography of scaling. In this case, Ribes is arguing on using scalar devices to evidence spatial scaling empirically(Ribes, 2014). Karasti and Bloomberg argue for a move away from spatial tropes in 'constructing the field' towards one that is multi-sited(Karasti and Blomberg, 2018). A more common thread has focused on the distribution of work across space and how it is structured. This distribution becomes centered due to co-location as enabled by digital technologies(Olson and Olson, 2000).

Despite the wealth of scholarship on spatial scope, little has been said on the navigation between different spatial scales. As mentioned earlier, the discourse has focused on linking the local to the global. This discourse, in effect, I argue, is a scaling discussion. The reframing of Star and Ruhleder's perspective of '*infrastructure as having reach and scope beyond a single event or one-site practice, both spatially and temporally,*' indicates scaling(Star and Ruhleder, 1996). Scholars Karasti and Bloomberg make the same argument through the connectedness dimension of infrastructures as they describe it(Karasti and Blomberg, 2018). Connectedness brings together different scale(Strathern, 1995), and for them, in the case of infrastructures, this is through standards. Ribes and Lee make a similar point arguing that studying standardization is '*to inspect the ways local diverge from a desired norm is managed, integrated and/or eradicated.*' Ribes and Lee further argue that focusing on standardization can help understand tensions between local and global practice(Ribes and Lee, 2010). Implicitly, standardizing is the practice of making something scalable. In a sense, as both Tsing, Ribes, and Lee argue, it enables either discarding of heterogeneity or management of difference and the integration of heterogeneity(Ribes and Lee, 2010; Tsing, 2012).

I, however, argue for spatial embeddedness as another mechanism through which scaling occurs. As described by Star and Ruhleder, embeddedness is a characteristic of infrastructures where '*infrastructure is 'sunk' into, inside of, other structures, social arrangments and technologies.*' I argue that spatial embeddedness is part of the connectedness dimension as characterized by Karasti and Bloomberg. Just as infrastructures are relational, so too is space(Strathern, 1995; Star and Ruhleder, 1996;

Howitt, 1998; Karasti and Blomberg, 2018). Through this frame, scaling is achieved through the active embedding made possible due to place and spatial networks. I demonstrate three ways through which spatial embedding is present in the SS project through spatial locations, spatial networks, and human activities. Spatial embeddedness is situational and drives us towards understanding how infrastructures navigate multiple scales more than a simple scalar collapse of the global versus the local.

Embeddedness is a term that finds its roots in the work of economic historian Karl Polanyi(Polanyi, 2001). For Polanyi, embeddedness describes the idea that one cannot fully understand the economy without considering the social and cultural worlds it exists in. There are social, cultural, and institutional dimensions that forge and define the economy of a place. The economy is embedded into social structures. This seminal piece laid the foundation for economic sociology and also found its way into economic geography, among other disciplines. Granovetter extends the notion of embeddedness to highlight how it comes about, especially through social networks(Granovetter, 1985). He argues that social networks determine and define some actions; therefore, they become embedded in the context of economic actions.

However, of interest in this chapter is the framing of embeddedness from the geographic perspective. The social nature of economic processes and their manifestation in space have primarily been the economic geographers' subject. This view means that embeddedness is a form of territorialization. For instance, as mentioned earlier in the literature review, the territorialization and the embedding of movie production and

infrastructure in Hollywood or New York's positioning as the global financial capital. Hess is critical of this view of embeddedness as it focuses on the local and localized social networks(Hess, 2004). Though I agree with Hess's critique on the over-territorialization of embeddedness, I use it to distinguish how scaling occurs and its use as a scalar strategy in infrastructural development. As Edwards argues for understanding how infrastructure navigates across scales, using embeddedness as evidence of scaling enables us to uncover the different scales(Edwards, 2017). In the next three sections of this chapter, I delve into the three forms of spatial embeddedness of spatial locations, spatial networks, and activities as spatial.

4.1 Spatial Locations

In this section, I draw out how place or location manifests a form of spatial embeddedness. Within CSCW, there is substantial literature placeness in the context of digital collaboration. A wealth of scholarship based on Harrison and Dourish's work has grown since the formulation of placeness in digital systems. They argue that place is space with cultural expectations and behavioral expectations: "*space is the opportunity; place is the understood reality(Harrison and Dourish, 1996)*." Suchman, also writing from a digital media perspective, highlights the contextual nature of plans and actions as being situated(Suchman, 1987). However, within CSCW, there are criticisms of this approach as it separates the physical world and turns to a view of it as abstract. Brown and Perry object to this perspective as it not only separates the physical material world from its meaning but also as it disregards the creation of meaning on-site(Brown and Perry, 2002). Despite the critique on both sides, spatial embeddedness is present. From

any of the two lenses, specific space opportunities allow for the making of meaning contextually. So too is the perspective of place as abstracted space as it speaks to the enactment of space.

In the SS project, one form of evidence of spatial embedding brought about by space is the use of bridges and other water infrastructures as sites for sensor installations. It was a hot and humid February day when I walked into the West Emergency Management offices to meet Oliver, the county emergency manager. As an emergency manager, his role entails coordinating emergency response in the entire West county working with federal, state, and local officials. On the spatial scale, the political scale demarcated as West county refers to a territorialization of where part of his agency extends. This territorialized agency also makes him very busy and reconciling our biorhythms to be able to meet to conduct the interview was challenging. Eventually, we managed to meet at the county office for an interview.

Oliver briskly walked in, quickly saying hi as he walked into his office. Since joining this project, never in my experience have I seen Oliver not busy. He is either moving from one meeting to another, coordinating with different people, meeting local politicians, and working with other public safety departments. After some five minutes, he shouts. "*Hey, I am ready now. Sorry, I am very busy, and let's see how I can be of help to you.*" He began by telling me how he got involved in the sea level sensor project. However, what stood out is what he said was the challenges of space this site presents. To him, Hurricane Irma was a game-changer as that was their second hurricane back-to-

back. *"We needed a better solution to triage our infrastructure and, more specifically, our bridges.*" His emphasis on the bridges is not by chance. As part of their emergency response, when there is a hurricane event, his team has to inspect bridges that have 'been touched' by flowing water.

The inspection of bridges takes a while as staff members have to traverse different bridges and report back bridges that seem to be close to being submerged, if not already. Nevertheless, for them to carry out bridge inspections, Oliver highlighted the challenge of relying on a single data source to decide which bridges to inspect. He stated, "*Whenever we have a hurricane event, we need to inspect bridges that have been touched by water. Just relying on one tide gauge at Fort Norad didn't really give us a good picture of how flooding was impacting the area.*" The tide gauge he is referring to is a sensing instrument located at Fort Norad. The purpose of the gauge is to measure sea level by measuring the ocean tides. Several gauges are installed across the coastal United States, allowing the National Oceanic and Atmospheric Agency (NOAA) to collect tidal movement data. More on tidal gauges later.

To deal with the challenge of relying on data from Fort Norad, the SS project installed DIY sensors on several bridges and some decks. The location of DIY sensors on bridges is evidence of spatial embedding. Oliver mentioned that one of the main reasons for this project was to *"inspect bridges that have been touched by water."* This inspection is made possible through the installation of DIY sensors on the bridges and other related infrastructures such as canals and other water-related infrastructure. This directness in

installing these infrastructures on bridges is not by chance. It is a form of infrastructural embedding.

As a place that floods frequently, the need to continually monitor water levels is high, as this information is essential in emergency response. One of the challenges in collecting data across Dosta and West county is the complex hydrological system at this site. The network of rivers, swamps, marshes, and topography makes this site complex, thus necessitating a novel monitoring infrastructure. Installation on bridges entails spatial scale workings in different forms and is a testament to spatial embedding. It is vital to understand the hydrological system's scale as this determines the extent or scope of the sensor installation. Parts of the county without dense hydrological systems do not have as many sensors. Also, the likelihood of bridges being in those parts is rare.

In addition, the hydrological system's spatial scale in this South-Eastern part is not similar to that of the road and bridge infrastructure. Bridges are gateways through which local communities connect. These connections do not occur at the same biogeophysical scale as the scale topographic and hydrological systems occur. Therefore, bridges and water infrastructure also operate at their spatial scale, mainly as human connectors. The installation on bridges means that the distribution of bridges limits the sensed environment's reach and scope. Similarly, the scope and extent of bridges are limited to the hydrological scale, amongst other human factors such as population distribution.

Spatial embedding brought by the installation of sensors on the bridge is present in three ways. In one way, the location of sensors on bridges is a physical embedding where sensors are 'sunk' into bridge infrastructure. In this form, the sinking is material. In the second, the network of bridges around West county defines the spatial scope of this infrastructure. Lastly, bridges do not just occur as there are conditions that support or necessitate this infrastructure. If we were to see nature as infrastructure, I argue that bridges are embedded in natural and hydrological scales.

A more complicated form of spatial embeddedness present in the SS project is the location of tidal gauges. More complicated in that as part of the digital infrastructure, embeddedness on a cursory look seems to be immaterial. The location of tidal gauges in the SS project is highly situated. As mentioned earlier, the tide gauge at Fort Norad plays a vital role in the project. In the project, embedding through tidal gauges occurs in several ways. One way is in the role that visualizations, data, and digital technologies play in making scalar jumps. For Oliver, readings and visualizations are a mechanism to make sense of how to plan the inspection of bridges. He needs to plan to see where inspecting should take priority and where he should send his staff first. As he stated: "*That was evident when we saw lots of different areas being flooded that weren't previously flooded or as severely as we had during Hurricane Matthew. So, there's a very different scenario between those two hurricanes, and we just needed to have more information as to how water was interacting with our environment.*"

Oliver's work entails looking at the gauge's readings through digital infrastructure and translating those readings to make sense of where he thinks it is flooding. In his workflow before the SS infrastructure setup, the Fort Norad gauge visualizations became embedded into emergency response aiding in making inferences on flooding around the county. This employment of data at a single location on the coast to make inferences about a county is a scaling form. In this form, a scalar jump is made from one lone sensor to make propositions about flooding around the county. Also, in the context of scalability is the framing of scaling as an extension of use. This form of scalability is present in the sense that Oliver also utilizes the tidal gauge at Fort Norad, primarily used by NOAA for monitoring tidal levels at the ocean to monitor flooding across a larger geographical scale. Ribes and Finholt point to this as a design for use position(Ribes and Finholt, 2009).

Another way spatial embedding is characteristically different is the notion of distributed cognition facilitated by the digital. I primarily draw on Edward Hutchins' scholarship within the discipline of STS, who posits the idea of 'cognition in the wild' referring to human cognition in its natural habitat(Hutchins, 1995). He contrasts this to say cognition in a laboratory where the environment is considered controlled. Through the development of the SS project infrastructure, what the digital affords is a one-stop site where sensors deployed across the county register data, custom models used to process that data, and results eventually used to extrapolate to more precise scales. Similar to a plane's cockpit, part of this new information infrastructure is a set of tools that scale down the sensed realities 'out there in the wild' onto an interface. This one universalized

view of the conditions is also a scaling mechanism because the interface allows for a generic picture that is zoomable, allowing one to jump from the coarse to more granular scales. The framing of the interface as a dashboard is a testament to the construction of cognition.

The installation of the DIY sensors on bridges presents another unique form of scaling, drawing us to navigate several scales. Similar to the scaling occurring where Oliver applies propositions made from Fort Norad's data to the county scale, so too are propositions made from the DIY tidal sensors to other smaller scales. Doris, a member of the project team, also mentioned the challenge of making inferences about the county from data collected at Fort Norad. She is well aware of the challenges as her work entails working with Geographic Information Systems, which is mostly the forte in manipulating and representing space. As a team member well-versed in GIS systems, she prepares datasets and analyses for the project team other than working for the Metropolitan Planning Commission (MPC). She highlighted how her work involved working across spatial scales, especially given the MPC's role of reconciling zoning and planning plans between the county scale and the city scale. When discussing why this project and the team were working on getting a sensor network, she mentioned that the problem is that what they get is a "*very general prediction based on that one data point at Fort Norad.*" She made the case that by having more data throughout the county, she bets that the more point data the project has, the easier it will be to "*extrapolate that into areas.*"

Here, I argue the framing and use of the term 'extrapolation' is a form of scaling. Similar to the scaling from Fort Norad to the county scale, the use of tidal gauges and their installation allows for scaling from one installation to a more precise area around its location. Explicitly the creation of more accurate flood maps, which are unique and distinct scales, is illustrative. Also, the collection of more data and the reframing of this issue as a big data problem speaks to the element of scale as quantified. However, what I think is more revelatory about this embedding and the scaling it enables is the dynamic creation of scales, in this case, flood maps. The creation of flooding maps dynamically is done through a downscaled regional model and other algorithmic procedures.

However, it is essential to highlight the discontinuities and fissures that come about from embedding as a scaling practice brought about by bridges and tidal gauges, as evident in the SS project. Take one case of the tidal gauge at Fort Norad as being embedded in emergency response that also finds its way into the SS project. For Oliver and his team, the only site or tool available to get a rough idea of flooding across the country is the single tide gauge. Though the tide gauge is very useful in measuring sea-level rise, the use of readings from the Fort Norad gauge to extrapolate flooding across the county is error prone. In the summer of 2019, Oliver took us through his process of determining where flooding occurred. He pulled up the NOAA website through a screen share showing us what he looks for in the NOAA data portal. However, what was revealing during that walkthrough was that occasionally he has to look at the readings from the tide gauge in the neighboring Northern state as readings from that gauge are better in making inferences about the upper part of West county. In this sense, findings at

the Fort Norad gauge are not transferable or applicable to parts North of the county. Thus, the need to deploy more DIY tidal sensors inland for Oliver to obtain a more accurate picture as data is collected at a higher resolution.

Similarly, the embedding of DIY sensors onto the bridges also brings with it certain discontinuities. As the project scaled from few sensors, the deployment of sensors mostly focused on areas close to Dosta and Kingston Island. As the geographical distribution of bridges in the county is also not even some areas that needed higher resolution data were left out. In two cases, the team made installations on docks that sat on private property. The decision to install on some docks points to the spatial embedding deficiencies resulting from utilizing bridge infrastructure that the team opted to use docks in some instances. Given there is a mismatch between the territorial scales of bridges and its use as a scaling opportunity, embedding occurs through other means. An individual's personal dock is used as a site for the embedding to occur in this case.

Most of the discussions thus far have centered on the regional and other forms of localized scales. The discussion on embeddedness brought about by the gauges and bridges has focused on the scale of these structures without attending to how they are operationally and institutionally territorialized. I mean, the discussion has focused more on who is 'sunk' into what without revealing how the what is governed and at what scale. This framing is inherently a scaling position as the team deals with enlisting entities of higher scales to achieve scale. That is vertical scaling, unlike scaling as obtaining greater geographic reach. Take the case of the tidal gauges under the authority of NOAA, as

mentioned earlier. As NOAA operates at a national scale, the distribution of these tidal gauges across the coasts is affected. The design of tidal gauges as instruments is operational at the national scale. Tide gauges are housed in a tide house as the enclosure is situated close to the coastline. Several highly specialized equipment, both for measuring and communication, are installed in the enclosure, allowing for accurate data collection and transmission. The devices operationalized at this scale are costly thus limited in installation. The cost implications affect the scale of operations and determine the scale and extent to which the gauges' installation occurs. Speaking to Dr. Smith, this scale issue became crystallized when she stated: "*That is pushing our science forward because there are big gaps in our understanding of things at that level because we haven't invested, of course, as heavily in that scale as we have at the global scale and even the tide gauge scale.*" Dr. Smith, the co-principal investigator in this project, has a wealth of experience in environmental modeling.

I make two key takeaways from the statement made by Dr. Smith on defining a tide gauge scale. This framing of the tide gauge scale reveals two distinctions. In one, the control and institutionalization of tide gauges under NOAA. The demarcation of the tide gauge scale highlights the national approach in monitoring tidal movement. This control and institutionalization are made possible through NOAA, who are custodians of these sites. At the global scale, scholars and different institutions use satellites to measure sea-level rise. In the second, the observational scale at play prescribes the scale of operation. In this form, as an agency tasked with tidal infrastructure at the national scale, the geographical extent of their work is limited in scope. In addition, this infrastructure is

also limited to the spatial boundaries ascribed to it institutionally. That is, some operations are limited to boundaries with the ocean. The same could be said about bridges as the SS project reached out to agencies such as the Ventria Department of Transportation to obtain their approval to embed the sensors on bridges that they are custodians of.

In the section above, I demonstrate how spatial embedding enables scaling to obtain greater geographic reach and increases the number of sensing sites. I demonstrate how the project actively embeds some SS project components onto bridges, docks, and tidal gauges to scale up. Also, I draw on Young's perspective of scaling to highlight how scaling occurs as propositions transfer to another scale(Young, 1994). I also highlight how embeddedness reveals how infrastructuring navigates different scales. In the next section, I focus on the role of spatial networks as sites for spatial embeddedness.

4.2 Spatial Networks

Here, I focus on the role that spatial networks play in enabling embeddedness. Unlike place and locality, spatial networks as locations that mediate flow enable a distinct form of embeddedness. However, before delving deep into spatial networks, I turn to highlight network embeddedness. Network embeddedness, as described within social theory in economics, refers to the structure of an entity's relationship with other entities, precisely the extent to which an entity connects to others or the interconnection(interconnectedness) between entities(Granovetter, 1992; Nahapiet and Ghoshal, 1998). Redundancy is essential in considerations around network

embeddedness(Echols and Tsai, 2005). Dense networks are highly redundant thus have great embeddedness(Echols and Tsai, 2005). It is due to high interconnectedness in a dense network that it engenders greater trust and familiarity.

In the case of spatial networks, the structure of the constituent elements of networks — edges and nodes — is on the basis of space. According to Barthélemy, spatial networks refer to "*networks for which nodes are located in space equipped with a metric*(Barthélemy, 2011)." This distinction gears towards the mapping and representation of the network as two-dimensional and not necessarily planar. He argues that what this definition does is make the case that spatial networks are not necessarily embedded in space. He provides the example of the representation of someone's social network. He, however, argues on the unavoidability of planarity of infrastructure networks. Here I demonstrate how spatial embeddedness is present and enables scaling during the development of the SS project. I am making an explicit connection between the embeddedness of existing networks that allow other infrastructures to be embedded to obtain scale. An example, for instance, is the use of underground sewer networks as internet supply ducts. I demonstrate how the SS project utilizes gateways and lift stations as mechanisms of scaling up the number of sensors and the infrastructure's geographical reach.

When I got the chance to interview Dr. Davis, he revealed the importance of the embeddedness of network gateways. Dr. Davis is a research scientist at UoD's School of Computing and lives in Dosta. His lived experience of Dosta was fundamental to the initiation of this project as he is acutely aware of the challenges confronting residents in

Dosta and the wider West county. I argue that as someone who lives and understands Dosta well, this is a form of embedding. I highlight more of this form of social embedding enabled by space in the next section. However, it was a warm afternoon when my advisor and I walked into the Energy building at Spring Square to meet with Dr. Davis. After waiting for a while outside the fifth floor, we found him in a meeting working with his colleagues. They were working on making hardware improvements to the sensing kit. After some searching, we found a room to sit down to chat, and it was in the interview that he mentioned the need to deploy the sensors and the gateways. He used the term coverage to define this. He stated: "*Yeah, yeah. To give us the coverage. Right? Well, I kind of skipped to the gateway problem*".

Dr. Davis's use of the term 'coverage' is instructive of embeddedness, particularly how embedding infrastructure into space occurs. However, other scholars, such as Harvey, use the term spatial fix to highlight how capital accumulation results in the need to occupy space(Harvey, 1981). Scholars such as Buier demonstrated how the development of green infrastructure through the Spanish Railway system is also a case of a spatial fit(Buier, 2020). As described by Dr. Davis, coverage is a term with profound implications more significant than just occupying space. For Dr. Davis, coverage refers to the geographical reach or scope of the sensors and the gateways. However, unlike sensors, gateways are distinctly different as their pivotal role is to support the scaling up of the sensing infrastructure by supporting more sensors and extending the SS project's geographical reach. Gateways allow for scaling the network and infrastructure and, in turn, affects how sensing kits become embedded into space. They allow this as they allow

for easy data transmission from the different sensing kits. For Dr. Davis, deploying a sensor network entails deploying not only the sensors but also the infrastructure to support the transmission of data from the sensors. When building such a network, the project evaluates the deployment of sensing kits and gateways through network architecturing, a common practice in computational science.

The SS project utilizes a low-power wide-area network to transmit data from the sensors to a central repository that is the server situated at UoD. A wireless network is required to facilitate data transmission from sensors installed across the county. Transmission is done through gateways as sensors by themselves do not have the physical properties to transmit data covering a large spatial area. Additionally, because the sensors are low power, they are not physically capable of transmitting over long distances. Gateways make data transmission possible as they act as bridges that route data traffic between sensors and servers and make low power sensing feasible at the sensing end. Their higher power ratings and special radiofrequency equipment allow for greater geographical reach, scaling. The deployment of LoRaWAN (a technological standard) gateways allows for the increase in reach and scope of data transmission. Hence Dr. Davis's use of the term coverage. However, gateways' location is also highly calculated to maximize the spatial reach of the network. These peculiarities I consider to be an essential form of spatial embedding. That is, the location of gateways really matters.

Ribes argues that scalar devices are crucial in understanding how an infrastructure scales(Ribes, 2014). I argue that gateways are scalar devices as they increase the

geographical reach and scope of the infrastructure and support more devices and, more importantly, device heterogeneity. Gateways act as scalar devices allowing for networks to grow in two primary ways. In one, they step up radio frequencies to allow for better data transmission rates. They enable better network proximity as proximity to the gateway enables better data transmission. The sensor data visualization on the dashboard map also reflects data transmission by indicating when the last data packet was received. It is possible to tell which sensors are offline and when the last data packet passed through the gateway. Proximity, as also argued by Barthélemy, is an essential factor in planar networks as it helps in determining embeddedness. In this form, mathematical proximity calculations help determine how close an entity is to other sensors. As scalar devices, gateways have to sit somewhere, and where they sit determines scalability. How they are embedded is crucial.

Gateways make use of standards and protocols that allow for scalable networks. As mentioned earlier, in the first case (proximity and coverage), they ensure that nodes are accessible. In the second, they allow for heterogeneity of devices. This form of device heterogeneity is present in the sea level sensor network through the LoRaWAN standard. The project team now also has some air quality monitors using the network to transmit air quality data. These two devices — the DIY sensors and the air quality monitors — are evidence of this heterogeneity. More than this, support for heterogeneity is also the support for more devices. A substantial increase in device numbers means that gateways must be ready to handle the increased data traffic. Thus, an increase in sensing kits means considerations about how the scalar increase will result in gateway demands. An

overwhelmed gateway is a clear indication of the need to scale the network through some more gateways.

However, more important to consider is another facet in using the term 'coverage' when we speak about gateways. As Dr. Davis stated that their priority was to "*look at the map of the county, and work with the city and county engineers and identify which is the infrastructure we want sensors on.*" This determination of sensor location is crucial as it forms the first step in defining the network's spatial bounds that they were building out. The next step after this was drawing out where to position gateways to serve those sensor locations. The positioning of gateways is a product of not just the spatial reach defined by sensor installations but also by other factors that the team weights. One such factor is what many in radio frequency networks call 'line of sight.' The installation of gateways needs to be on sites where radio waves could be easily transmitted and with little degradation to maximize reach. The example mentioned presents two unique forms of spatial embedding evidence different from the more straightforward form where entities occupy space. One is the topography and the second is the actual physical property of the gateway. As topography is heterogeneous, installing gateways in some sites will yield better results than others. In the second challenge, the physical properties of the gateway are essential to consider. Gateways are designed and have a power rating and frequency reach. By transmitting through a specific frequency band, they have better spatial reach. For example, the network router at home transmitting through a 5G frequency has different capabilities than a gateway serving an entire campus block.

What I am drawing to here is the embedding of gateways in the network. Gateways are 'sunk' into networks as they operate in the background facilitating data transmission between sensors and the server. They are the silent workhorses facilitating connections between entities on a network. It is gateways that enable dense networks bringing about high embeddedness. Without gateways, it would be challenging for sensing kits to communicate with each other and the central repository. So not only are they embedded in the network, but they also facilitate embeddedness.

In the SS project, another more complicated form of embedding occurs by sinking the SS infrastructure onto existing networked infrastructures. Unlike the use of bridge infrastructure, as mentioned in the previous section, I focus on the network effects of the underlying infrastructure and the capabilities afforded by such infrastructure. By revealing how such infrastructures afford some distinct capabilities, I also focus on the socio-spatial embedding given the territorialization of sites where embedding occurs. Here, I demonstrate how unique structures in West's sewerage system called lift stations are sites where the team installs some gateways. I argue that utilizing such already existing infrastructure and embedding it into the SS project is scaling.

Gateways, unlike the DIY sensors, have higher power demands. The material structure of these two devices is distinct. The DIY sensor's power source is through batteries that last for a long time, and also small solar panels are attached to recharge the batteries. Powering these devices is trivial, unlike gateways, which draw more power and need a consistent power supply. As gateways need more power than sensors, they become

embedded in other infrastructures that already have power access. That is part of scaling the sensing network entails sinking some components into other infrastructure capable of providing continuous power. Without reliable gateways, scaling the network becomes even more challenging. Other than access to power, the other factor is if the site (where embedding occurs) has reliable power and has backup power, especially as the county is prone to hurricanes. Speaking to Dr. Davis, he described the initial challenges of deploying the gateways as having "*some fits and starts*." He stated: "*We looked at libraries and school buildings. That was originally the plan, but the reality of working with the facilities people who control those buildings and the fact that they all have different networking, and they all have different policies. That turned out not to be the right approach.*"

Contrast the approach the team took in utilizing schools and libraries to utilizing lift stations. In a sense, Dr. Davis explained how difficult it was to scale through libraries and schools than lift stations. During our interview with Dr. Davis, we got the chance to speak about lift stations and why he ended up doing installations on lift stations. Dr. Davis mentioned that lift stations are part of the sewer infrastructure as Dosta is so "*flat and there is no downhill for the water to go to when it leaves your drain, and so it has to be pumped.*" He continued: "*And so at 92 locations in the county they have what's called a lift station, and it's literally a pump to pump the sewage along, to keep the sewage flowing.*" The number and distribution of lift stations were vital as they enabled the easy scaling of the network. Scaling in the material form was made easier in one way by taking advantage of the topographical features and, in the second, the sheer numbers of

the stations. As lift stations as situated on slightly higher ground on the landscape, they provide a better 'line of sight'. Unlike schools or libraries that may sit on lower ground, the geographic reach provided by a higher elevation is more extensive through lift stations. With 92 locations as sites where embedding could occur, the scale that the team could obtain using these sites is greater than schools and libraries.

However, perhaps nothing perked our ears when he further pointed out why lift stations came in "*handy*." He stated: "*First off, they all have a telephone pole there because they have an antenna on top of that for their control equipment, so we can get up high. And they all have backup generators, because they have to work in a storm, so they have backup power. And they are... If you look at a map of how they're... They're this fantastic geographic dispersed around the county. Right? I'm like, "Ah!" So, if we can get the team that manages those on board, then we can pick ten of them and use that as our infrastructure.*" Dr. Davis's description reveals more about how embedding can engender scaling. However, scaling is not just due to the spatial distribution of the lift stations but also due to site affordances. However, what is distinct about this form of spatial embedding is that Dr. Davis tries to overlay his network onto already existing infrastructural networks. However, tactically, he is also upscaling his network by aligning his network to existing networks to benefit from the grander scale. He works to overlay his network onto another already established network as a form of unique spatial embedding.

However, spatial embedding detailed from the case above is much more than the characteristics and capabilities afforded by such network infrastructure. I turn to the social aspects of such sites as thinking about the social also reveals more on embeddedness as a scaling strategy. As mentioned earlier, Dr. Davis stated that the project erred in its approach of using libraries and school buildings as opportunities for embedding to occur. In essence, Dr. Davis surfaced the challenge of locating gateways as much more than an issue of managing space but also managing socio-space. This challenge is present in two ways. In one, the distribution of such infrastructure (schools and libraries) is spatial. Secondly, the activities and human infrastructure at these sites also affect the spatial scale of the network. He did eventually get one school to install one of the gateways, but this was not scalable. Scalable not because of the numbers but rather the social structures and arrangements around these institutions.

In the context of spatial scales, the use of the term '*control*' defines territory. Working to scale from the library scale was challenging as the distribution of territories is dense, and those who control these territories are independent and varied. The heterogeneity and agency at the library and school scales result in a condition that makes these sites more difficult to embed socially. Contrastingly, lift stations are sites where the city's sewerage department holds agency over these spaces. For Dr. Davis, lift stations were a mechanism through which to overcome the bureaucracy that he initially faced when he approached schools and libraries. As the city is also a partner in the SS project, it is easier to have scalar alignments as a scaling strategy, therefore, easier to obtain scalar fit. Dr. Davis summarized this strategy by highlighting the aspect of control and agency by mentioning

how he ended up discovering lift stations. He summarized that he did this by posing the question, "*what is a resource that the county owns, can control, or the city, that we could possibly use for this?*"

The control over the social embedding of infrastructure is important to consider here. As the county and the city do not have much say on how libraries and schools operate, they are not as tightly embedded as the city's sewerage department. For the SS project, the need for socio-spatial embeddedness is necessary to be able to scale. Not only from a perspective of access but also the affordances of the sites where embedding occurs. As Dr. Davis mentioned, later on, gaining access to the lift stations was easier. Once the city's manager learned of the need to access the lift stations, he quickly prepared a letter and instructed staff to help the project in installing the gateways at the lift stations.

In the section, I have delved deep into how networks enable infrastructural embeddedness. I have also demonstrated how this form of spatially networked embeddedness can be tactically employed to be able to scale. The use of gateways and lift stations highlights how these two components present different forms of scaling. The different scaling forms include supporting more devices, supporting device heterogeneity, and increasing the geographic reach of the infrastructure under development. However, notably is the piece about when embeddedness fails to provide a scaling opportunity. I detail how libraries and schools were sites that the project explored to scale up, but challenges faced resulted in finding alternate sites. The reasons why libraries did not work out as great scaling sites were due to the poor social embeddedness of that

infrastructure due to agency and control issues and spatial embeddedness issues as the infrastructure at such sites was highly heterogeneous non-uniform. The material arrangements at these sites were very different.

In the next section, I turn to activities as spatially situated and embedded and how these activities engender scaling or non-scaling. Though these activities I could characterize them as a form of social embeddedness, I strive to draw how place plays a significant role in shaping such activities. The spatial scales involved in these activities constitute the essence of the respective activities.

4.3 Human Activities

Several scholars within CSCW have demonstrated the embedding of human infrastructures onto infrastructures under study. Lee et al. make the argument on how the human infrastructure leverages existing technical and social arrangements from similar projects as an example of embedding(Lee, Dourish and Mark, 2006). Human infrastructure to them refers to the arrangements of "*organizations and actors brought into alignment for the accomplishment of work.*" They build their understanding of embeddedness based on Star and Ruhledger's notion describing it as the condition where infrastructures depend on a range of existing technical and social structures for identity and function. Though several authors have illustrated how human infrastructures span across space and time, there exists a gap in framing this form of embeddedness as a scaling question. This gap exists despite the discourse on how human infrastructure

mostly responds to local needs and regularly entails working to meet such requirements while at the same time working towards a greater effort.

Though I spend a considerable amount of time in one of the chapters on what it means to scale a human infrastructure, I attend to embeddedness in this section. Specifically, I focus on human activities and the socio-technical arrangements around these activities to highlight how embeddedness may engender scaling. I focus on two activities of calibration and surveying as two examples where socio-spatial embeddedness is foregrounded and is part of an infrastructure that develops with time.

In our interview with Jack, he explained to me in detail the calibration process that they undertook. Jack was involved in several aspects of this project. In one, he was involved in working with Oliver to develop the sensor dashboard. Earlier on, he was involved in dealing with uncertainty issues by using statistics to compare readings from the sensing kits. He situated how calibrating is an exercise in working through different spatial conditions. Addressing the issue of uncertainty entails working through spatial challenges, scaling, and rescaling. He explained to me that the fundamental question around uncertainty was, "*how do we know our readings are correct?*" Given the deployment of these novel sensors and the tide gauge as the ground truth, the need to "*standardize*" was central. The use of standards and the creation of standards entails doing scale work. As Star and Ruhleder emphasized, standardizing in infrastructures is the mechanism through which the tension between local and global resolves. Just as

infrastructures are relational, so too is scale(Howitt, 1998). Standardizing is an exercise of creating such relations.

How are the readings at the tide gauge related to the data collected by the DIY sensors? Jack specifically used the term '*ground-truthing*' to describe this. He stated: "*Additionally, a lot of our uncertainty calculations are compared to what we call a ground truth.*" He explained that in the sea level sensor project, the ground truth "*is the NOAA Fort Norad tide gauge.*" He delved further into ground-truthing when I asked him what it means in practice. Seeming annoyed by my question, he paused and said, "let's *take a step back*." "*The first thing is to get our sensor readings and convert them to the NAVD88 datum*". Of course, I had come across the datum before as a dashboard team member, perhaps why he seemed irritated. The NAVD88 datum is a data standard used for vertical control surveying in the United States. Within the Americas, it is the measurement unit for sea level. The use of the NAVD88 standard allows for a comparison between the DIY sensors and the tide gauge readings. He used the term "*apples to apples"* comparison. By employing the same scale, it is possible to benchmark measurements across the county and allow for comparability. Benchmarking makes it easier to look at readings from a DIY sensor west of the county directly compared to the NOAA's tide gauge readings.

However, it is crucial to distinguish the concepts of embeddedness and standardization. In the case of calibration, the standardization allows for easy embedding. It is a form of rescaling where readings occurring at the Fort Norad gauge are translated

to a standardized scale to allow for what Jack calls an "apple to apple" comparison. For the project to perform this comparison, embeddedness occurs where Fort Norad's reading becomes embedded into each DIY sensor's readings. Evidence of this also translates to the visual representational forms of charts showing DIY sensor readings. Interpreting the chart of one of the DIY sensors entails comparing it to the reading at Fort Norad. Embedding occurs due to Fort Norad's wave chart's superimposition on each DIY's sensors tidal wave chart. The interpretation of readings at one local site also entails the interpretation of readings registered at Fort Norad.

Other than using the same datum and the same scale, ground-truthing is also done by collocating two DIY sensors at Fort Norad. That is, two DIY sensors became embedded at Fort Norad. At Fort Norad, the team installed two DIY sensors at the tide house that shelters the expensive tide gauge instruments owned by NOAA. At this collocation site, a translation occurs, enabling the team to identify differences between the readings from the DIY sensors and the tide gauge. As Jack finalizes, "*I think the biggest issue ends up being that with this whole network of sea level sensors, only two of our sensors are colocated with a sensor that is of much higher accuracy, which is that Fort Norad tide gauge. So, then it is a question of how much can we extrapolate our understanding at that one location, at Fort Norad to the entire network of sensors.*" With the ability to compare readings simultaneously (the same site) and reducing other externalities, the team engages in a kind of spatial scaling. Differences identified between colocated sensors and tide gauge readings are useful as scaling involves extrapolating them (the differences) to the rest of the network. Differences discerned at the tide house site are applied to the rest

of the network. In the context of infrastructures and scales, applying differences at the local site (Fort Norad) to the rest of the sensors installed across the network demonstrates how embeddedness fosters scaling.

Nothing perhaps may drive this home due to a discussion during this workshop on scaling from Fort Norad to the rest of the network. Participants discussed the mystery of four inches that Jack and Dr. Smith discovered due to colocating two sensors to the tide gauge. Four inches are negligible to them, but some readings seemed incorrect when translating them across the network. As Jack stated: "*We actually had an issue with, like everything is surveyed, so the vertical elevation of the sensors is surveyed to the top of the sensor box, then we have to change that elevation to the bottom of the sensor box, where it's actually taking the readings. We actually were doing that calculation incorrectly at first. So, it actually turned out that our sensors were very accurate and any issues we were seeing at the beginning when our data at first when it was off, it was actually due to human error.*" The team resolved the discrepancy after realizing the installation team carried out some elevation surveys at the bottom of the sensing kit instead of the top of the kits. After identifying the problematic sensors, the team carried out a re-survey.

Surveying is another activity carried out in the SS project that presents a unique form of embeddedness. Surveying involves examining and recording features of an area and translating those readings into other forms. Plans and outputs of surveys do not exist in themselves. They are scalar devices allowing for a form of tangible, easily transferrable

representation, and in the digital form, easily altered. The product of a survey exercise is a scalable representation. Maps produced from surveying are useful in demarcating boundaries and relating those boundaries into other physical forms, such as building plans or zoning plans. In the most basic form, surveys allow for the abstraction of space and facilitate scalar jumps. Take the case of building plans. As products of surveying, they allow for the navigation of several scales as they are approved at the city, shared with construction crews, altered by architectural firms, and shared with clients. Plans are abstractions of space represented on paper detached from physical space.

Take the example of the sea level sensor projects where Josh explained in detail the building permit process. For Josh, the building plan is an accurate representation of a building scaled down onto paper with relevant information. Josh was one of the members from the city who became involved with the project from the get-go. As a floodplain manager, his work is to approve building plans to ensure that the plans meet the local city ordinances. There were several documents at the building entrance, ranging from building permit forms, public works forms, application for inspection, electrical wiring guides, and many other forms. I picked a couple of forms to go through in my free time. On one end of the building entrance, a lady was seated behind a transparent window helping a construction worker file some documentation. The construction worker, clad in heavy boots, an orange reflector jacket, a heavy pair of worn-out jeans, and a construction helmet, quickly walked away from the teller. She mentioned that he was missing some documents motioning him away from the counter.

I eventually was let in through a steel door as Josh came to pick me up. We sat in his office, which had several flood maps plastered on the walls. It was while speaking to Josh that he revealed how his work entails dealing with space. He stated that part of his work when he gets the plan is to "*just make sure that that house is built in accordance with our ordinance.*" The building plan is an architectural document that is a representation of a building drawn to scale. It is a two-dimensional conceptual framing of space. In this form, on a cursory level, surveying results in building plans that enable a unique form of scaling. That is an abstraction allowing for relaying information on the ground and what is to occur without being on-site. Surveying is a process that leads to embedding in the physical world when framed from the perspective of embedding objects or buildings onto space. For embedding to occur, an abstract mental model in the form of plans fosters collaboration and governance, thus being scalable.

However, a more critical form of embedding is the form where plans and surveying as socially embedded. Such processes produce unique distinct languages and representations, enabling a standard frame of understanding. As a scalable process, city permitting officers, construction crews, and others involved in the process understand this common language. In the case of permits, permits are embedded in space and time. They are also socially embedded in practice. At the governance scale, permits document the city's authority while building plans constitute the common language of how those standards apply at the local level. Here, in this form, standards result from this embedding as in the physical sense, local ordinances and standards are made from the ground up.

A case that highlights how embedding results in standards is when the city checks elevation levels on building plans. As a floodplain manager, besides making sure building plans meet local ordinances, he also checks for the building's elevation. Elevation as a construct is made present due to a socio-technical process of measuring and understanding topography. Survey equipment allows for the taking of such readings as they connect to global satellites, enabling the representation of space on a three-dimensional plane. This representation of space enables the measurement of topography. Josh pointed to the role elevation plays as he gave an anecdote where he went to survey and inspect a building only to realize that the minimum floor elevation was off by just a tenth of an inch. He stated: "*I actually had to get up underneath it and lift the slab up little bit. We made them elevate.*" It is crucial to contextualize why elevation as a way of understanding space is essential, especially in a place like Dosta. Elevation checks as part of the permit process have only become part of this standard in the recent past due to flood insurance and climate change risk. Meaning, it is the embedding that preceded this change in the standard. Evidence of embedding preceding the standard is the adoption of the NAVD88 standard as a mechanism to compare building elevation data in relation to sea-level rise.

In this section, I have focused on embeddedness in the context of the social and human. I have illustrated how calibration and surveying activities as spatial practices present different forms of embedding engendering scaling in different forms. However, it is essential to acknowledge how this framing looks at how activities are embedded as

being different from the general “where activities occur” question. Though many questions are still unanswered, I specifically take the spatial-social activities as they inherently entail working across many local sites and navigating several scales. That is, some activities are inherently trans-scalar. For instance, calibration in the SS project entails incorporating readings across other local sites. More questions than answers surface due to this framing highlighted here. I argue perhaps for a move away from prescribing activities as local as this leads to a form of local trap. The description of activities as occurring only at the local level leaves out how activities traverse different scales, especially at the local level.

In this chapter, I detail how spatial embedding engenders scaling. I draw out the utilization of embeddedness in the SS project as a scaling strategy. However, it is essential to distinguish how scaling through embedding is remarkably different from standards as scaling instruments. Embedding in the first frame, as discussed here, deals with the idea of where things sit. That is how things or activities get ’sunk’ into space or place. The second frame deals with how infrastructure gets sunk into other infrastructures or structures. Through the framing of embeddedness as a form of scaling, we are able to reveal the multiple scales that infrastructuring navigates. Standards, on the other hand, are seen as scale agnostic applicable to all scales. Embedding as a scaling strategy entails the diligent contextual assessment on how to utilizing existing structures to obtain scale. Also, unlike standards, embedding does not seek to discard heterogeneity but rather seeks to build upon. In sum, standards are about protocols, while embedding as a scaling strategy considers placeness to obtain scale.

CHAPTER 5. TEMPORAL SCALING

Scale in the temporal sense, unlike in the geographical, is not as contested. Several scholars have highlighted the role of temporality and temporal rhythms in infrastructure studies, STS and CSCW(Ribes and Finholt, 2007; Jackson *et al.*, 2011; Steinhardt and Jackson, 2014). Jackson et al. make the case of different temporal registers in collaborative work, pointing to the ongoing alignment to bring them to function at the local scale(Jackson *et al.*, 2011). Scholars such as Ribes and Finholt explore the temporal dimensions of infrastructure, particularly highlighting three things that constitute scales of infrastructure. The three concerns are institutionalizing, organizing, and enacting technology. They also explore the tensions across these three scales(Ribes and Finholt, 2007, 2009). Karasti et al. build upon Ribes and Finholt's work to argue that an infrastructure occurs by resolving the tension between the short-term and the long-term(Karasti, Baker and Millerand, 2010).

Like the tensions articulated by Karasti et al. and Ribes and Finholt, tensions also exist in the SS project. One tension present is between the long-term climate resiliency issue and the short-term disaster response issue. As an infrastructure, the SS project has to meet these two needs, one for the county and the other for the city. In this case, this tension is synergistic as the infrastructure and data collected for the short term are essential for longer-term climate modeling. As argued by Karasti et al., an infrastructure occurs where the tensions between the long-term and the short-term are resolved(Karasti, Baker and

Millerand, 2010). This argument builds on Star and Ruhleder's view that an infrastructure occurs where tensions between the local and the global are resolved(Star and Ruhleder, 1996). However, the tension mentioned is also a symptom of tension caused by the different infrastructural uses. Ribes and Finholt, in their analysis of varying cyberinfrastructure projects, articulate how designing for use may present tensions between communities and constituencies(Ribes and Finholt, 2009). In the SS project, the team designed the infrastructure for disaster response, flood monitoring, and climate resiliency. This design for this use case attends to the needs of the community that coalesces around this infrastructure. However, the same project also engages with a local community interested in air-quality monitoring using the same infrastructure. In this use case, this small local community represents a constituency with different needs from the rest of the community. As an infrastructure, the SS project meets both the needs of various constituencies and the community simultaneously. The practice of resolving such tensions is a practice of scaling, I argue. In the example above, meeting the needs of the constituency and the general community constitute scalability.

In this chapter, I argue that infrastructuring is much more than resolving tensions between the short-term and long term. Karasti also makes a similar point putting forward the interplay of the two as synergistic. My contribution explicitly makes the argument that the linking of the short-term to the long term is a form of temporal scaling. Scholars such as Lemke ask, "*how do moments add up to lives?(Lemke, 2000)*" I reframe the position of Karasti et al., Ribes, and Finholt of infrastructure as occurring when resolving tensions as a manifestation of scalability or scaling in practice. That is, resolving tensions

is making something scalable. Therefore, resolving tensions between the short and the long-term is a form of temporal scaling.

Another more nuanced contribution I make is that infrastructuring involves much more than resolving tensions. That is, temporal scaling entails much more than linking the short to the long term. I argue that a different form of temporal scaling entails the translation of propositions from one scale to another. As Oran Young writing within the environmental humanities provides an example of temporal scaling where the scaling up of propositions on interannual climate variability could tell us about climate variability at the decadal level(Young, 1994). In summary, temporal scaling entails applying propositions from one temporal scale to another and usually mediated through clock time.

In this section, I utilize rhythmanalysis to demonstrate how three different temporal registers or scales(Jackson *et al.*, 2011) constituting the SS project become aligned through clock time. This alignment to clock time enables scalability and is what I consider a form of temporal scaling. I highlight the temporal registers or dimensions of phenomenal time, digital time, and human/social time as scales aligned to enable infrastructural scaling in the SS project. The use of rhythmanalysis(Lefebvre, 2004) is essential due to its temporal embeddedness, transcendental and immanent properties. Other scholars such as Orlikowski and Yates highlight how rhythms are critical in sidestepping the individual versus collective temporal experiences(Orlikowski and Yates, 2002). Rhythms also enable the movement away of ascribing temporality between entrenched divides such as universal/particular, linear/cyclical, natural/social, open-ended

vs. closed(Orlikowski and Yates, 2002). As Jackson et al. also argue, rhythms enable us to account for the role of non-human actors and forces in how time is socially constructed(Jackson *et al.*, 2011).

I want to emphasize and reiterate why resolving tensions is a form of scaling and how I get to that position. To contextualize this, I start from discourse within infrastructure studies where the notion of 'tension' first appears. Star and Ruhleder argue that "*an infrastructure occurs when the tension between the local and the global is resolved.*" It occurs when "*local practices are afforded by a larger-scale technology usable in natural ready to hand fashion.(Star and Ruhleder, 1996)*" In this view, the use of technology or infrastructure at the local level is varied and flexible while rigid at the global level. In a sense, it entails linking the universal at the global to the local's particulars and peculiarities. The local is highly situated. Scholars such as Karasi et al. build on this perspective of tension, showing in their case how tensions arose with the introduction of a standard to several local settings(Karasti, Baker and Millerand, 2010). Discourse within infrastructure studies has largely framed this resolving of tensions as a process of standardization. Similar to Karasti et al.'s framing of this tension linking the local and the global through a standardization frame, Star and Ruhleder argue that standards "*reach beyond a single event or one-site practice(Star and Ruhleder, 1996).*" Also, they say that through the embodiment of standards, infrastructure becomes connected to other tools and infrastructures in a standardized fashion, thus being transparent(Star and Ruhleder, 1996).

Discussions around resolving tensions between the local and the global have centered on the tactical linking between the two scales through standardization. For example, in the case Karasti et al. provide, they highlight how the development of the standard entailed augmenting it to fit local practices while also transparently plugging into other infrastructure(Karasti, Baker and Millerand, 2010). Tensions, I argue, are a manifestation of something not being scalable. Something or practices at the local scale may not be easily translatable to the global scale; thus, tensions arise. I argue that resolving such tensions is a scaling practice or making something scalable. In the context of scaling within infrastructure studies on the temporal dimension, infrastructure occurs when tensions between the short-term and the long term are resolved. Adopting a similar framing of scaling and resolving tensions as detailed above, resolving tensions between the short-term and the long-term is temporal scaling. Contrastingly, if standardization is how the local and global become linked, how is the short-term linked to the long-term? Alternatively, what form of standardization is present between the short and long-term? Here, I argue that clock time as a standardization enables temporal scaling.

I now turn to three different temporal registers demonstrating how they link the short-term to the long-term. I also show how clock time is useful in mediating different rhythms across the infrastructure. In the next section, I focus on phenomenon time as a temporal register.

5.1 Phenomenon Time

As highlighted in the literature review, several scholars characterize nature-based temporalities as either phenomenal or as natural time. Jackson et al. writing on the collaborative rhythms present in infrastructures draw us to the phenomenal rhythms present, dictated, and emanate from the objects of study(Jackson *et al.*, 2011). This character is part of ecologically centered infrastructures like the SS project. In contrast, Karasti et al. specifically use the term nature time to refer to naturally occurring temporalities(Karasti, Baker and Millerand, 2010). Scholars such as Karasti et al. highlight how temporal scales are diverse and point to the example by understanding nature as operating in its own temporal rhythms and scales. They present the model of nature time by drawing in Smith's (Smith and Goodin, 2003) work, emphasizing climate variability issues, and the temporal scales at play that ecologists need to put center.

However, Jackson et al. argue against the use of 'natural' time as phenomenal time best describes the imposition of rhythms for an extended or truncated period. They point to the field of political science as one that is determined and constrained by the four-year election cycle. I build upon the notion of phenomenal time to demonstrate how phenomenal rhythms are part of the SS infrastructure and how they come to matter when we speak about temporal scaling. In a sense, they are not only rhythms that are managed and manipulated through infrastructure by bridging tensions between the short term and the long term, but also the translation from one temporal scale to another. I demonstrate how such rhythms play a role in linking the short-term to the long term and how they are translated from one temporal scale to another through clock time.

It was not until I sat with Oliver that he mentioned how living in Dosta and working as an emergency manager entails understanding some natural lifecycles. As part of his work, Oliver has to deal with one form of phenomenal rhythms: tidal movements occurring at the county's coast. In his lived experience as an emergency manager, he has seen cases where high tides have cut off some communities necessitating road closures or, in severe cases overseeing the evacuation for some families. To keep track of ocean tides, he uses data from the tidal gauge at Fort Norad to make sense of tidal levels. Based on the gauge's readings that he accesses through the NOAA website, he can have a proximate guess of where flooding occurs. However, the reliance on this one sensor does not present realities on the ground. The realities on the ground, as described by Oliver, are based on human observation and experience. As a scale problem, one sensor location is not very useful in providing accurate information on where flooding occurs across the county. Meaning that responding to floods is based on experience and what he considers "hunches."

Several participants framed this information lacuna (that is, flooding and water movement) as a visibility problem. One sensor at Fort Norad is insufficient in providing an accurate and precise picture of tidal movement and flooding across the county. Their personal experiences also account for the evidence as they would visit some sites thinking that they were flooded only to discover that they are not, and, in some cases, the reverse was the case. The challenge of visibility is why the SS project is vital to him, as with more DIY sensors; he has a better sense of water movement across the county and

the tidal flows. He stated: "*So, we only had the Fort Norad Tide Gauge, and that's how we had to make decisions of where things are going to be. We'd also look at the storm surge modeling and look at that potential inundation graphic and see which areas are going to flood.*" He explained how that one sensor to check the tides was not enough. He continued, adding on why timing is essential. "*However, that's not going to give us the timing associated with that, and that timing is really a critical component, especially due to our lack of resources.*"

For Oliver, the reliance on that one sensor at Fort Norad and using data it registers complicates time-based decision making. In situations where emergency response is considered urgent, the lack of clear and precise data hampers decision making. Infrastructurally speaking, a collection of DIY sensors across the county collecting tidal data are useful in reducing uncertainty leading to more accurate and precise interventions. In characterizing tidal movements, team members view tide events as having a lifecycle. This view is not just unique to members of the project team. To be able to monitor coastal flooding, it is crucial to keep track of tides and their lifecycles. Tides are part of nature as they refer to the rise and fall of sea level due to the combined effects of gravitational forces exerted by the Sun and the Moon and Earth's rotation. The combined impact of the three determines the strength of the tides and the lifecycle of the wave. Also, as the project entails studying the matter of long-term sea-level rise, it takes on a phenomenal rhythm. Tides and tidal movement form part of the object under study.

As these tides are central and are part of the object of study, they constitute phenomenal rhythms. As rhythms part of SS infrastructure, they do not display the

tension between the short term and the long term. They seem to be easily aligned. In the short term, the collection of data on these rhythms is essential for emergency response. In the long timescale, they provide a framework for understanding and studying long term sea-level rise. Even though we were to zoom out from the rhythm level and look at it from the lens of project time and infrastructure time as posited by Karasti et al., the project's short-term aims align with the long-term purposes of scientific knowledge production and climate mitigation(Karasti, Baker and Millerand, 2010). Contextually, temporal scaling is made possible through the sensors. Data collected for the near-term flood monitoring needs also constitutes data for climate change modeling, sea-level rise in particular.

However, the other form of temporal scaling I argue for is the translation of phenomenal rhythms into other states usually mediated through clock time. As highlighted by Orlikowski and Yates, temporal scales can be objective or subjective(Orlikowski and Yates, 2002). In the objective form, temporality is quantified, absolute, and measurable. The representation of tidal movements is typically through oscillation charts showing the rhythmic nature of tides. A "*sinusoidal wave*" is what Jack, one of the project members I interviewed, called it. The horizontal axis shows the tidal current, while the vertical axis shows the tidal crest's height. Given how we observe tides, ocean currents are highly situational. Each tide is unique and significantly different, given the various forces at play. Part of infrastructuring and measuring tides consists of finding patterns and standardizing. The "*sinusoidal wave*" exemplifies this standardization.

Jack described the process of getting the tidal measurements as consisting of getting readings and smoothing. A timestamp accompanies each reading taken by the sensor. Therefore, each data point collected indicates water height and the time it was recorded. The data is plotted on a graph and fitted as a sinusoidal wave. The project employs curve fitting algorithms to draw a clean sinusoidal graph, yet in reality, tidal movement is not as clean and non-messy. Through this process, the discarding of some data points occurs to obtain fit. This process is emblematic of temporal scaling in that phenomenal rhythms are translated into digital time to enable graphing. Project members can know if it is high tide or low tide without physically being present at the specific site through such graphs. I argue that this translation of propositions from one scale to another is also temporal scaling. In this form, phenomenal rhythms are recorded with a timestamp. Timestamps are essential as they facilitate the graphing of the waves, with the timestamps translating onto the x-axis. Timestamps are a form of clock time and are also a universal form for the representation of time. Due to the timestamps, the construction and identification of phenomenal rhythms enabling its translation onto other temporal scales occurs. An example of such a translation is how they affect biorhythms when an evacuation has to occur.

In the discourse around the subjective and objective temporal forms, tides have objective temporality as they are measurable. This objectivity is present in the SS project as the conversion of sonic waves to tidal heights is registered. In the subjective case, terms such as high tide or low tide are socially constructed. High tide refers to when the

sea level is the highest, while low tide refers to when the sea level is the lowest. Part of living in a coastal community such as Dosta that occasionally floods is keeping track of high and low tides. NOAA and other agencies produce tidal forecasts showing the specific time when tides will be high and when they will be lowest. Such forecasts are mediated through clock time.

Tides aside, other phenomenal rhythms are present in the SS project. As mentioned earlier, the moon phases also play a significant role in determining the strength of the tides. Unlike the relative distinction between high and low tides occurring daily, higher tides occur when there is a new or full moon. The moon's gravitational pull, also called tidal forces, results in higher tides. Thus, the moon's position relative to the earth results in varying tidal forces that in turn affect tides. However, the world is also not just an actor inactive in this condition. The earth's rotation makes it more complicated as the moon's position and the planet are continually moving. This mix means that the recording of high tides is relative to the natural forces at a particular moment at a specific place. That is, tidal movements are also highly situated and relational. One could argue that this form of temporality is relational, thus being characterized as a form of relational time.

The combination of the earth's rotational rhythm and the moon's rhythms complicates how the local experiences tidal rhythms. As mentioned earlier, the astrological temporal scales have a role in determining tidal phenomenological rhythms. Astrological time scales determine how we observe and study these rhythms. For instance, to fully

understand tidal rhythms well, one also must account for other factors, such as the moon's rhythms. In the context of temporal scaling, how we comprehend tides entails scaling the moon's rhythms to the tidal temporal scale. How this phenomenon is understood is due to the translation of astrological temporalities to tidal temporalities. Also, there are both subjective and objective forms of temporality in the moon's phenomenological rhythms. In the subjective form, descriptors used to characterize the moon phases such as crescent, full, half, or new moon manifest how we observe and describe it. As evidence for the objective form, the lunar calendar also enables temporal scaling as it is translated to clock time. It allows for one to make propositions about those astronomical rhythms without physically observing them. In the SS project, the lunar calendar plays this role.

However, nothing perhaps explains the moon's subjective temporal form, as evidenced through king tides. King tides are unique, given the position of the earth as it orbits around the sun. Having been involved with the project for a while, I had heard about king tides. I remember sitting with Mike, a software developer on the team when I asked him to explain in his own words what the king tide was. He seemed exhausted by that question as I think he knew I knew what it was. I spoke, emphasizing how getting his perspective on how he would describe it was necessary. "*This is exacerbated based on the orientation of the sun and the moon. If the sun and the moon are in perfect alignment, they will pull extra hard on that high tide causing something called king tide. In cases of king tide there may be roads that get flooded, even though it's totally sunny outside. Just because of how high tides and low tides work, because of sea level rise, those are higher*

than usual." By explaining the king tide, he went further to explain how the effects of sea-level rise would be worse. He continued: "*And some low-lying areas and marshy areas or roads that are very close to marshes or right at sea level and all that can have water encroach onto those and cause problems. That's sort of a blue sky of flooding example."* For most people exposed to the project, the term 'blue sky flooding' was not new. I had come across it in several presentations made in workshops and other public engagements. Blue sky flooding refers to floods that are a result of high tides.

Keeping track of king tide phenomena was critical to the project team and was also foregrounded through interviews with local administrators. When I sat down to speak to Josh, the local floodplain manager, he mentioned how he has to navigate and explain to residents the risks posed by king tides. He explained: "They can say 'Hurricanes don't hit me.' Well, we can sit there and say, '*Yeah, but if we have this king tide here, you're going to flood here.' That's a little more down to earth than somebody grasping for a type five hurricane coming through.*" A challenge of working as a floodplain manager is meeting occasional resistance to building plan ordinances. In this case, Josh explained a case where a resident objected to the regulation as they felt that they are not in a flood zone. However, given the area is prone to hurricanes, the resident stated that there was no need to meet the ordinance as they never experienced a hurricane. In this case, Josh had to explain how king tides, though not as bad as hurricanes, could bring about floods. King tides are a temporal reference useful as a language to describe specific high tide events. For the local population in Dosta and many coastal communities, keeping track of these

tides forms part of their lived experience affecting different facets of life, such as building a house.

Temporal scaling in the case mentioned above is present in two primary forms. In one form, the long-term consideration of king tides' effects given the underlying risk of sea-level rise occurs. In the short-term, building plans and approvals have to meet specific elevation standards, and enforcement brings about the city's long-term sustainability. The term resilience is also indicative of the local rhythms employed to bring about long-term sustainability. In the other form, temporal scaling is also made possible as the proposition that tides will be higher means that buildings need to sit on higher elevations. In this form, the tidal movement's phenomenal scale translates to the temporal rhythms involved when building and designing. These rhythms also become translated into the human temporal scales constitutive of the floodplain manager's role.

Unlike tides and the moon, the SS project also deals with hurricanes as another phenomenological rhythm. Given Dosta's low-lying nature and as coastal Ventria is in a region that experiences regular hurricane events, working and living in such an area entails preparation for such events. Hurricane temporalities are present in several ways. In one way, hurricanes in themselves are spatial temporal. Temporal in that atmospheric conditions lead to the movement of water through high winds, creating a storm. However, the scale of this kind of storm is not ordinary. Hurricanes are spatial temporal based on the actual physical movement across the landscape over space and time. The determination of the path the hurricane takes is essential in understanding the

temporalities present and how this temporal scale affects other rhythms. For instance, the multi-scalar ramifications that come about when an evacuation order has to be issued. The period from the storm's formation to the point when the storm dissipates represents its lifecycle and is also the hurricane's temporal scale.

A point made in presentations to local stakeholders on the importance of the SS project was that had Hurricane Irma just come five minutes earlier, the effects would have been severe. Dr. Brian would present a live simulation showing what would have occurred had the hurricane landed five minutes earlier. Simulations were essential as representations offered 'what if' scenarios helping crystallize the problem to the different audiences. Simulations present an interesting temporal scaling case where data collected on a hurricane is used to make propositions at another temporal scale. In the simulation mentioned, Hurricane Irma was rescaled to an earlier temporal scale, five minutes earlier. That is, the temporal rescaling of the conditions and rhythms of the hurricane as registered. Other than simulation, hurricane predictions are another form of temporal scaling. In a simulation, the condensing of the temporality of phenomenal rhythms to digital time occurs. An event that took close to twenty-four hours gets rescaled and represented in a shorter period, becoming playable as a movie in three minutes. In predicting, temporal scaling occurs as propositions about scenarios are based on registered phenomenal rhythms.

Other than hurricanes having innate temporality, another form of phenomenal rhythm is how local administrators have systems in place for "*hurricane season.*" The months of

August and September are usually regarded as “hurricane season” by local officials. It was last year in August (2019) when we worked on the dashboard, and we had to be mindful of how busy Oliver was. Getting a hold of him during that period was difficult as he was preparing for hurricane season, as he called it. In this season, the occurrence of hurricanes is more frequent. Oliver narrated how hurricanes affect local communities, and as the emergency response manager, he described how he has to juggle the various temporal scales. “*During Hurricane Irma, we had a lot of people that didn’t understand the threat of the hurricane and said, ‘Oh, I live 15 or 20 miles from the coast, I’m not going to evacuate, I’ll be fine.’ Those people quickly found themselves with several feet of water above ground in their location, and they had to be water rescued.*” For Oliver, hurricanes are challenging, especially as there is work that goes into preparing for the event, responding during a hurricane event, and then post-event where the local emergency teams assess the damage and help residents to get “*back on their feet.*” He added that as they do not have a ton of water rescue resources in the county, they need to develop a mechanism for prioritizing emergency response. This prioritization is where Oliver believes that the “real time information” installed by the project will come in handy.

The temporalities due to hurricanes lead to other temporalities. “*Hurricane season*” is a subjective temporal scale to Oliver and his team. There are no discrete dates or times, but rather a general sense based on their experience that hurricanes’ frequency is higher in those months. During this period, the Atlantic’s atmospheric conditions make for a potent mix that results in more frequent pressure systems. Easterly waves originating

from Africa are more developed, thus enabling their formation. The displacement of dry air in the eastern and central Atlantic by the African easterly waves creates room for cyclone development. These, among other factors, contribute to the formation of hurricanes. The frequency of the adverse weather events helps construct a temporal scale in this specific case. As a season, not only by event frequency but also by the human processes involved in planning for such events, the team defines a temporal scale. In the case of pre-hurricane, local administrators use data to evaluate actions such as executing mandatory evacuations. Post-event, the responders have to be urgent in helping residents "*get back on their feet.*" Disaster time could define the "*triaging*" of disasters, such as hurricanes. Oliver's work entails dealing with each specific disaster differently and working on longer-term disaster-related issues. Similar to Karasti et al., disaster time could be considered identical to project time.

The temporal phenomenological rhythms made possible by hurricanes are illustrative of temporal scaling. On the long-term scale, keeping track of storms in the 'now' is part of how the human infrastructure prepares. As mentioned earlier, there is a role history plays in how emergency teams respond. Based on past experiences, the emergency team is able to refine and make their decisions more precise. Oliver mentioned that after every storm, the emergency teams sit down to do a debrief to deliberate on areas to improve and acknowledge what went well. With every experience, the teams get better, and knowledge is created and shared. Temporal scaling occurs as plans are updated, response manuals updated, new data points collected, and biological rhythms reorchestrated, all pointing to preparation for future events. The reorientation of biological and social

rhythms also occurs. The framing of ‘hurricane season’ also speaks to the temporal scaling from the phenomenal to the human or social temporal scale. Translation onto the institutional temporal scale is an example as institutionally rhythms become re-prioritized during hurricane season. Clock time helps in the reorganization as the months of August and September are evidence of temporal scaling.

In the context of the long-term effects of climate change, some project members mentioned the possibility of more adverse and stronger hurricanes. As emergency response members are primarily interested in the present and operational on disaster time, climate change issues are not at the forefront. However, through the SS infrastructure, they attend to the short term and the long term because the same infrastructure used for emergency response facilitates knowledge production on climate change. In this section, I highlight how temporal scaling occurs in the phenomenal temporal register. I also demonstrate how clock time mediates between different temporal scales. In the next section, I turn to digital time as a temporal register.

5.2 Digital Time

Despite scholarship on temporality and the digital, scholars within CSCW and STS have done little to characterize the digital as a temporal register. Evidence of this is in the different ways scholars have used other terms to describe registers brought about by digital systems. Karasti et al., in their piece on infrastructure time, provide an example of other temporal scales. They refer to Internet time to highlight temporalities based on non-human ‘actors’ within digital or IT systems(Karasti, Baker and Millerand, 2010).

Schofield and Arrigoni introduce the concept of network time to attend to the temporality of networks(Schofield and Arrigoni, 2017). I specifically use digital time as such systems encompass much more than the Internet or digital networks. The SS project entails working with temporal rhythms and temporalities that constitute different socio-technical systems. One of the time scales present in the SS project is the notion of real-time. Within computation, real-time refers to the transmission of data with no delay. However, as a participant-observer in this project and based on interviews with different project team members, real-time is highly situational and subjective. It was after meeting Ethan that the situatedness and subjectivity of real-time became concretized. During my week in Dosta, I got the chance to meet Ethan in his office in February at HH. HH is a local non-for-profit organization that advocates for environmental justice issues, among other issues. Though situated in Dosta and local to Dosta, their reach extends beyond Dosta, to other regional scales, other national scales, as their work also extends to the international stage.

It was Friday on the week of the workshop that I went down to Hull to meet him at three pm that afternoon. I walked into this lovely quaint pink house in a residential neighborhood and, thereafter, proceeded to press the doorbell after taking up the steps. It has just drizzled though being in a coastal area; it was humid. As I stood waiting there, I could see a shadow behind the stained-glass door approaching. There he was, Ethan opened the door, welcoming me in. I clumsily walked in, not sure what to do with my boots as they were wet, and this seemed to be a lovely home that I did not want to get dirty. In a split second, I subconsciously removed my shoes, placed them at the entrance,

and followed him into the lounge. The room and the ground floor was adorned with art on the walls. He pulled up a chair and welcomed me as he took his seat. They had converted the lounge into an office with tables and office chairs occupying the space rather than couches and coffee tables. There is something to be said about the temporality and the temporal scales present at ethnographic sites. In contrast, to say an interview over Skype or other videoconferencing systems, physical access to a site could tell us more about temporalities. Here, in this house adorned with several artworks and pictures, stories and narratives could be revealed as they provide for moments to reveal other temporalities.

As one of the officers from HH, Ethan was crucial to the project as he works on civic engagement issues with residents. Given that part of his work at HH entails supporting residents, he mentioned that real-time information was essential to residents during the interview. He stated that as an organization involved in environmental justice for several years, the real-time monitoring of sea-level rise was critical as local communities had already seen the effects of a warming climate. When I asked him what real-time meant to him and why is real-time monitoring was of the essence in their work, he mentioned: "I'm *taking them at their word, but what the system will ultimately deliver is accurate up to I think plus or minus five to ten seconds of readings that are measured, confirmed within their algorithms and by testing with other sites and other sensors, and delivering that on the Internet in such a way where apps can be developed to the people can have real-time displays of current situations, down to the point where it would be accurate enough for the County Emergency Management Agency, the fire departments, and police*

the departments, as well as all other OSHA and EPA agencies, can use that data to reflect real-time decisions. Yeah, we're talking about honestly, not less than a 20 to 30-second delay of actual reading being displayed on a person's phone."

As someone initially involved as a developer in the project, my understanding of real-time was not in sync with his. In real-time emphasizes a view of the current conditions on the ground. The complexities and intricacies of the smart sea level sensor infrastructure and different information flow components do not reconcile with Ethan's framing of real-time. As a developer, there was a common understanding that the project was not really 'real-time.' Perhaps near real-time. For instance, the transmission of data from the sensors to the server occurs in five-minute intervals. Also, as the number of sensors across the network is not synchronized, the server does not simultaneously receive data from the sensors. That this, they all do not send data at the same time. One may send data at noon and send the next data packets at five past noon, while another situated elsewhere may send data at one-minute past noon. The data collected at the scale of the sensed environment is not temporally synchronized. Other factors that may play a minute role include gateway locations or sensor breakdowns. Also, the algorithm deployed only takes data snapshots every fifteen minutes, as described by Mike. A snapshot is also another form of temporal scale, as though frozen in time. Thus, whatever is on the screen is the output of a model that utilizes data collected fifteen minutes ago.

Similar to Ethan, Oliver views real-time information as essential in making decisions effectively. When I asked Oliver what real-time meant to him, he mentioned how during

hurricane Irma he wished he had better data to make operational decisions on where to send his water rescue resources. For Oliver, real-time information allows for "*better decisions*." Although the language that depicts real-time is commonly shared, real-time, as understood by different participants, is highly situational and subjective. For Ethan, he reduces real-time to a matter of seconds. On the other hand, Oliver sees real-time not as quantifiable but rather as the timely delivery of information. Also, as an ethnographer, my perspectives on what real-time is are characteristically different.

Real-time as a kind of temporality in the SS project forms part of the infrastructural accretion process that synergizes the short term to the long term. Real-time information bridges the short term and the long term by linking disaster emergency response to climate change resiliency in the broader sense. This bridging, a form of scaling, is through monitoring and record-keeping as information accretes. Even though participants may disagree on what is centered, this infrastructure occurs as it resolves tensions between different actors. For some, emergency response framed as "*saving taxpayers' dollars*" is more important than the long-term effects of climate change, which is the centerpiece for other participants or constituency. Also, short term flood modeling and flood zoning play an essential role in preparing for the exacerbation of flooding based on the effects of climate change. In the second case, temporal scaling takes a framing similar to that made by Young, who argues that scaling is the transfer of propositions from one scale to another. For instance, what does flooding that occurs at the moment tell us about flooding in ten years or over the long term? What does this short-term flooding inform the city about zoning laws and permitting procedures?

The term snapshot is also illustrative of temporal scaling in characterizing real-time. In this view, it is the scaling of propositions from a moment at a specific site that is highly situational to a temporal scale representative of the entire network. As explained earlier on the subjectivity and situational aspects of what real-time is, a snapshot represents a temporal scale where sufficient data from all the sensors have been received to provide a general picture around the network. It is akin to scaling of propositions from one sensing node to the network of sensing nodes. It is also a form of temporal territorialization where propositions at a sensing location become scaled to the entire county. In the case of the SS project, Mike pointed to snapshots to being fifteen minutes in duration. Scaling is made possible due to clock time, as real-time is a snapshot of conditions across the network. It is due to another temporality, timestamps, that translation from one temporal scale to snapshots occurs.

There is something to be said about real-time as a form of temporality and how social and biological rhythms become aligned. As mentioned in the literature review, scholars such as Irani et al. highlight the notion of plastic time(Rattenbury, Nafus and Anderson, 2008; Irani, Jeffries and Knight, 2010). Others such as Lindley highlight the place of immediacy and how other rhythms take on such temporalities(Lindley, 2015). More could be explored here.

Another distinct temporality present in the SS project is computing cycles that exhibits a different form of scaling. Computing cycles could also be seen as a form of machine

time as they demarcate how long it takes to run a computer instruction. As the processing of the regional model requires the resource of computing clusters, Dr. Brian passed on the model algorithm to the Euro-Mediterranean Center on Climate Change (CMCC) as they have the expertise and the resources to perform this kind of computing. The role of CMCC had been clear to me when I got involved as a developer but also arose during our interview with Dr. Brian. He stated: "*And then we have another guy who is the guy who is knowledgeable about multi-parallel computing and processing. One thing is to have a code that runs another is to make it efficient so that actually, you get some stuff out of it. So he's the guy that knows clusters and stuff like that.*" As the CMCC operates a cluster for global environmental modeling, the team relies on them as a partner to not only run the model but also structure the model code to operate efficiently across several cores. In technical computing terms, computing cycles refer to the time it takes to carry out an instruction. As algorithms are a series of instructions, computing cycles refers to the measure of how long execution takes. In parallel computing, due to computers having several computing units, the need arises to distribute instructions to ensure efficient use of all the units, resulting in shorter execution times.

Computing cycles link the short term and the long term through embedding. Other scholars within infrastructure studies have highlighted the challenges of dealing with the long now of infrastructures(Edwards *et al.*, 2007; Ribes and Finholt, 2009). The discourse around long term infrastructuring has primarily centered on sustainability and maintenance and the tension with meeting everyday needs(Lee, Dourish and Mark, 2006; Ribes and Finholt, 2009). CMCC's technical and social infrastructural embedding into the SS project highlights how the project balances both the short- and long-term ends. As

CMCC has a computing cluster and social expertise in global climate modeling, its incorporation into the project meets short-term modeling execution needs. For the long term, embedding provides the opportunity for meeting the maintenance and longer-term modeling needs of the project. Other scholars have highlighted the role of computation and computation cycles in framing scale and scaling(Ribes, 2014). Computing cycles represent a temporality of the computational execution of an instruction. As the infrastructure accretes and more data is continually recorded every five minutes, modeling for longer-term variability will take longer. More computing cycles will be required to process for more extended time periods.

Temporal scaling of a different form is also present due to computing cycles. I have detailed how computing cycles manifest temporal scaling as they link the long term to the short term through faster and scalable processing of data that accretes. I have also detailed how the project links the long term and the short term through the infrastructural embedding of CMCC's infrastructure. Infrastructural embedding allows for short term human and technical resource needs to be met and at the same time meeting the long-term sustainability and maintenance needs. However, another form of temporal scaling presented through computing cycles is the production of three-day forecasts. As mentioned earlier, one of the outputs from the computation of the models is a three-day forecast of tidal movement and flooding. This form of prediction is short term. However, short term predictions are also useful in determining issues of climate variability over longer temporal scales. Though the project at the moment has not yet translated the forecasts to the long term, Dr. Brian mentioned how in the future, the prediction outputs

would be useful for longer-term forecasting and for identifying climate variability patterns. To do this kind of scaling, the timestamps when data was collected are useful, highlighting the role clock time does in facilitating this scaling.

Another unique form of digital temporality present in this project is latency. Latency in computational science refers to the time it takes for a data packet to move from source to destination. Latency is represented in milliseconds or seconds and is vital in network architecture. One of the first tasks given to me in this project was writing code that maps distances from gateways to sensing nodes. Based on latency values and transmission speeds, I determined which sensing nodes have to transmit data over very long distances. All sensing nodes are programmed to send data every five seconds. This rhythmical sending of data every five seconds I consider a data transmission rhythm. Dr. Davis noticed that there was a transmission delay from some of the sensing nodes, and the exercise I carried out was to identify areas where another gateway would be needed.

Moreover, latency is also relational. Latency values are seldom constant as local conditions such as weather and line of sight issues affect transmission rates. For instance, transmission rates deteriorate in adverse weather conditions, especially when it rains. Or even power at the sensing nodes does affect transmission. Poorly charged nodes are not able to draw enough power for transmission. This degrading or delay also has a cascading effect on creating snapshots useful in the execution of the regional model. Latency as a temporal scale surfaces temporal scaling in a very distinct way. As scaling the network either through extending its geographic reach or the number of sensors is a form of

infrastructural accretion, latencies help bridge the long-term to the short term. Latency does this as it supports both the maintenance of the network and its development as new sensing nodes come online. Meaning, I was instructed to carry out this process as some sensing nodes seemed to be unreliable, thus part of maintenance. However, this process was also instructive as it helps in scaling the network, thus developing the infrastructure. As latency is based on clock time, it facilitates this form of temporal scaling.

This section has highlighted different forms of temporal scaling of digital time as a temporal register. In considering digital time as a temporal register, I present three forms of real-time computing cycles and timestamps and how they link the short-term to the long-term. I demonstrate how this linkage of the short-term to the long-term is a form of temporal scaling. In the next section, I look at temporal scaling on the social and human register.

5.3 Human or Social Time

In this section, I demonstrate how temporal scaling is present through social and human temporalities. I focus on the social and human rhythms that constitute the SS project are aligned and bridge the short term and the long term. Additionally, I also highlight how the mediation of scaling occurs through clock time. I focus on two forms of temporalities, political temporalities, and institutional temporalities. Scholars within CSCW and STS have indirectly focused on temporal scales relating to humans. While there has been substantial research on time and temporality as social, agreement amongst researchers has been elusive(Adam, 1994). In the literature review, I delve into the concept of social time and its social construction.

During my first workshop in Dosta, the then-mayor gave a speech to close the day's proceedings. Given that the mayor was a republican, he mentioned that the city should be daring and, rather than fret about climate change, be proactive by building sea walls outside at sea. "*Netherlands have done this. Why not just build massive sea walls out at sea?*" The engagement of the city administration with the project was not considered strong at this particular point. Engagements were not as close though connections existed, albeit loose. However, that all changed when Dosta held local municipal elections in late 2019, where a new city administration would come into place. With a change in administration, the project team scheduled another meeting with the new city officials to bring them up to speed with the project.

My experience at that workshop was telling. It was perhaps not until I interviewed the city's sustainability officer who was part of this project that more became concrete. It was during this interview when I asked him about the project and navigating the political landscape. He stated: "*Yes, so we just experienced a pretty significant shift in our council makeup as of November of last year. So, starting January, we have a council of nine, seven of them are brand new.*" He went on to explain the main focus of the previous mayor was on emergency response and that he was less concerned with the long-term issues of how the sea level sensor project would "*inform, build environment strategies and infrastructure development.*" However, the new administration for him view the emergency response component as also essential but secondarily have longer-term interests. Perhaps, it is because it is a new term, he demurred.

As someone who spent time at this site, political tensions occasionally surfaced. Tensions such as the focus of the project diverged based on the political scale and audience in front of the project team. To the county team, emergency response was most important. An active participant in the interviews described the project as essential in '*saving taxpayer dollars*' as it helps direct resources to areas that need it most. To the team at the city, long-term issues such as sustainability and community emergency preparedness were more critical. However, as an infrastructure, the SS project resolved both tensions by meeting both the disaster response needs and meeting the city's long-term climate resiliency needs. To emphasize, the political tensions present between these two political scales are also political temporalities in tension. As an infrastructure, the project team is able to translate an emergency response infrastructure into one that meets climate resiliency needs, therefore a testament of temporal scaling.

Political temporalities are not just present in resolving the long and short-term tensions. Political terms are temporal rhythms that point towards leadership change. As mentioned by one of the participants, a change in political leadership at the city scale helped more towards longer-term issues such as building resilient infrastructure and working on other environmental issues. A simple change in political terms was able to unlock several possibilities. The city administration at this state was just new with a fresh four-year term. The opposite was also true as, after the meeting with local Dosta city officials, we went to have a meeting with officials of West county administration. Physically we were moving from meeting an administration operating at a city scale to

another operating at a larger geographic scale. Rhetorically, a metaphorical form of scaling. At the county meeting held in a conference room, several county administration members from different departments were present. In the room was one of the county commissioners who keenly followed the proceedings. However, it was not until the end of the meeting that Oliver mentioned to colleagues at the table that there is nothing much the commissioner could do as elections were just around the corner. County commissioner elections were to occur in June, and with only four months to go, commissioners usually do not make any decisions. It is as though they are running the clock down. Here, clock time links and demarcates political terms allowing for political outlooks with different temporal scales. In this case, a change of terms entails rescaling either from short-term to long-term or vice-versa.

It is essential to highlight how political temporalities translate into other temporalities in the project. A good example is the extra alignment work done to synergize biorhythms with political temporalities. As a member of the SS project, meetings with different political leaders occurred at different sites. Meetings with county representatives only involved county representatives, and meetings with city officials only had city officials in attendance. These briefings never occurred in the same room with both leadership at both political scales present. For the project team, this entailed making the same presentation to both groups separately. This tension meant extra articulation work that entailed synchronizing calendars, reserving rooms, and reorienting the focus of the presentations. Though presenters made efforts in ensuring the slides were the same, small, subtle nuances in the slides and presentations were evident. For instance, the foregrounding of

the collaboration with HH seemed to be prominent in meetings with the city, unlike the county meetings. The biorhythms involved in this project were oriented based on the political temporalities.

Given the scaling problems political temporalities present, institutionalization is another temporality that does the opposite. Among the issues that political temporalities present in infrastructuring is sustainability. To counter this issue, infrastructuring in the SS project enlists institutions and actors within those institutions as mechanisms to address sustainability issues. By focusing on institutions, the effects of political temporalities become tapered down. It is also at the institution level that the short term and the long term become synergized. An example in the SS project highlighting the critical role institutions play is the Metropolitan Planning Commission's (MPC) role. For the SS project, it is possible to attend to both the short term and the long term simultaneously, as evidenced by the MPC.

In my interview with Doris, a member of the project team who works at the MPC, she highlighted how the institution's involvement could bridge these two temporalities. She also stated that the aligning of climate change resilience to emergency response diminished temporal tensions. In the case of the long term, Doris stated that planning is a long-term process. As someone who works at the Metropolitan Planning Commission (MPC), the MPC makes plans in 30, 50, or 100-year intervals. "*In terms of time scales, longer is more desirable for planning, like the sea level rise viewer from NOAA doesn't show you what sea level will look like 30 years out, 50 years out, 100 years out, but it*

shows you at different levels of sea-level rise, one foot, two-foot, three-foot." For Doris, resiliency is a long-term goal, while the emergency response process is short term. "*With Dr. Brian's model, his ocean model, that gives a three-day forecast, which is more useful time scale wise, to someone like Oliver or emergency managers, who are going to be making more short-term decisions.*" For the SS project, the long-term resilience and planning issues align with the current emergency response activities. In the previous section on digital time, I have illustrated the temporal scaling brought by prediction.

For Doris, the MPC as an institution works on bridging these two scales. However, what is essential is the framing of urban planning as an activity that is long-term oriented. Longer time scales in the context of planning are desirable, and institutionally, this kind of planning within Dosta and the West county occurs at the MPC. However, this does not mean that they do not deal with day-to-day routines short term in nature. As explained by Doris: "*Right now, we are about to start going through an update of our comprehensive plan. Like this month, I think we're going to start, sorry. Just based on the very basic conversations we've been having, our director wants us to have a resiliency piece to each chapter of the plan. Resiliency as it relates to transportation in the county. Resiliency as it relates to housing. Resiliency as it relates to land-use decisions.*" She continued: "*Within that resiliency piece in each of those chapters, we can bake in use of the portal, and say things like, any amendments to the zoning map, which is an official map that has been adopted by the city and the county, any amendments that are proposed to that map, when reviewing those ... What's that called?*". She posed as she tapped her fingers on the table and blurted out, "*Applications.*" She further explained that as part of the resilience

piece, government officials would look up at the portal when citizens and locals place applications and check how applicants are likely to be affected in the long term. Though at the moment, long-term aims such as resiliency are not visible in the daily moments, Doris sees the dashboard infrastructure as something that could help relate the long-term effects of climate change to the present. For government officials, using the dashboard in decision making will become part of their daily routine, including considering long-term effects such as sea-level rise in deciding building permits.

As an institution that carries out zoning and planning for Dosta and West county, it enables temporal scaling as it aligns long-term resiliency needs and the short-term routine permitting needs. By being part of this SS infrastructure, it is able to look at long-term needs and translate them to the immediate zoning needs through amendments to local ordinances and permitting applications also brought into alignment with resilience goals. This scaling is facilitated through clock time as the institution makes plans over 30 and 50-year intervals. Therefore, evaluating the zoning and permitting process's small routines occurs as constituting a longer-term temporal scale while also influencing the short term.

Another institutional temporality that I consider is this site's role and the SS infrastructure as a part of a long-term scientific knowledge production site. For the project, daily routines include infrastructural development by working to scale the infrastructure. However, more than infrastructural development, the SS project enables the production of knowledge on the long-term effects of climate change. By building this

network of novel sensors, assessing longer-term questions on climate change is possible due to infrastructural accretion. This accretion means finding longer-term funding cycles or even enlisting doctoral graduate students in knowledge production for the project itself. Scaling here is much more than linking the short and long-term, but rather entails reconciling biorhythms to institutional rhythms or even funding cycles commonly represented in clock-time form. A five-year grant is capable to deployed to pay for a graduate student's doctoral degree.

In this section, I have highlighted how social time in the form of political time and institutional time present forms of temporal scaling. I also demonstrate how clock time mediates scaling as it enables an easier translation from one scale to another. Here, I specifically focus on how clock time mediates between the short term and the long term in the SS project.

In this chapter, I focus on the idea of temporal scaling, framing it in two distinct ways. In one, I argue that linking the short- to the long-term is a form of scaling, and tensions do not necessarily have to exist for this scaling to occur. Though, I do argue that resolving tensions between the short-term and the long-term is temporally scaling. I also draw on Young's definition of scaling to argue that temporal scaling entails the application of propositions from one scale to another scale. In this second framing, the translation of propositions of temporal rhythms at, say, the astrological time scale onto another temporal scale such as digital time is temporal scaling. I argue that clock-time facilitates temporal scaling as it is an abstraction of time. In the double framings on

temporality, both build upon the infrastructural accretion. In the long term, it is the temporal quality of 'accretion' as infrastructuring is incremental, contiguous, and often dyssynchronous(Anand, 2015; Karasti and Blomberg, 2018) that demonstrates how the short becomes the long. Similarly, other scholars such as Lemke ask, "*how do moments add up to lives?(Lemke, 2000).*" In the second temporal scaling framing, similar to how we ask how we move from a local scale to a regional scale, I explore how we move from one temporal scale to another.

One of the things this piece does not do a great job with is exploring the view of time as infrastructure and what this means to the notion of temporal scaling. As Edwards argues that infrastructures, including physical ones, display modularity, scaling, and networked organization as properties, there is more to be explored on how time as infrastructure reflects scaling(Edwards, 2017; Besedovsky *et al.*, 2019). Would this also be temporal scaling?

Another critical issue that I need to acknowledge that I have not centered in this piece is the place of history in the context of temporal scaling. Especially in the contextualization of the Anthropocene, the history of the 'age of man' and industrialization is essential in contextualizing scaling. It is how we are able to answer the question of "*how did we get here?*" Bowker makes a similar argument on the need for historiography that is produced through the mapping of the temporalities of infrastructure(Bowker, 2015). In studying infrastructure projects such as the SS project, there is the role of experience and shared history that acts as a base for infrastructural

development. Though participants mentioned how history got them to this specific site or mentioned how other projects lead them to this project, the relationship between history and temporal scaling could reveal more if explored.

CHAPTER 6. SCALING HUMAN INFRASTRUCTURE

In this chapter, I delve into the question of scaling from a human infrastructure perspective. As stated earlier in the introduction, I argue that doing away with scale also means doing away with scaling as the two concepts are intrinsically linked. Especially from an ecological perspective the two concepts are highly related. Within the context of infrastructure studies, scaling in one way is presented as a characteristic of the connected dimension of infrastructures(Karasti and Blomberg, 2018). Scaling, as defined by Ribes and Lee, especially in talking about 'scaling up' refers to a quantifiable concept where there is an increase in 'the number of collaborators, the quantity of data, availability of raw computing cycles or broader geographic reach(Ribes and Lee, 2010).' Others view scaling as an extension in terms of the spatial or geographical reach, temporal reach, or the local-global(Edwards *et al.*, 2007). Edwards views scaling as an inherent quality of infrastructures(Edwards, 2017).

However, unlike scaling through computing cycles or more sensors, scaling human infrastructure is unique. The modularity present in computing systems and memory chips is not the same in humans. Scholars such as Woods argue that the human is unscalable(Woods, 2014). Lee et al. introduce the idea of human infrastructure, referring to it as encompassing the social practices that support technical enterprise(Lee, Dourish and Mark, 2006). They approached this notion of human infrastructure, referring it to the people, organizations, networks, and arrangements that form a collective entity. Though the authors did slightly touch on how to scale such collaboration, they did highlight how new and old organizational structures shape human infrastructures. The authors surface

how personal connections play a role in scaling the human infrastructure. Other scholars operating within CSCW also make similar claims highlighting the role of personal networks and connections in scaling human infrastructure. For instance, Nardi and others highlight the role of shared history and emergence in scaling up human infrastructures(Nardi, Whittaker and Schwarz, 2002). Engeström et al. use the idea of "knots," referring to loosely connected networks of people(Engeström, Engeström and Vähäaho, 1999).

Despite the wealth of scholarships on the role of personal connections and networks, I build upon Lee et al. position that personal connections are not sufficient in accounting for how human infrastructures are built and maintained. There is an oversized, taken for grantedness role ascribed to personal connections. In this section, I build upon Ribes' concept of scalar devices to demonstrate how scaling is performed in human infrastructures to bring about the emergence of connections, maintaining those connections, or as part of knowledge production practices. I highlight how scalar devices play a role in developing connections and maintaining them(Ribes, 2014). In this form, scaling entails adding new members to the project. However, I additionally highlight the scaling strategies involved in making connections. Here, scaling is much more than adding members to the project. I attend to the intentional work and process of contextually adding members due to their access and power within specific scalar contexts. This latter form of scaling is highly contextual.

This chapter highlights how scalar devices act as tools for bringing about co-operation or emerging new connections where personal connections did not exist. As mentioned earlier, this provides another framing through which to see how developing human infrastructure can occur devoid of personal connections. I then highlight how scalar devices also act as instruments in maintaining such collaborations. The existence of personal connections does not inherently mean the sustaining of that collaboration. Lastly, I highlight how scalar devices act as tools for knowledge generation.

In sum, there are two main contributions here: One is extending scalar devices as a mechanism to understand the scaling of human infrastructure, showing how they act as tools for enabling emergence, maintenance, and knowledge production. The second contribution highlights that scaling human infrastructure is much more than adding more participants but rather involves a contextual calculating scalar strategy where considerations also focus on the participants' scale of operations. This framing means that the reach and scope some potential participants have access to also plays a role as this is essential in embedding human infrastructure.

To emphasize the aforementioned two contributions, I would like to draw you to why and how these two contributions are unique. In the first contribution of scalar devices as tools for scaling human infrastructures, I focus on the question of how to scale human infrastructures. In the literature, especially in infrastructure studies, there is a lacuna on how one can scale human infrastructures. Current literature on human infrastructures has primarily emphasized the role of personal connections. Other scholars such as Lee have

highlighted that accounts of personal connections can be lacking as they are deficient in accounting for human infrastructures. It is here that I specifically use Ribes' concept of scalar devices, which he argues that it is a methodological mechanism of understanding scaling. My primary moves here are two-fold, I provide empirical work supporting the use of scalar devices to understand how human infrastructure is scaled. Scalar devices do this in three ways. One, they allow for the emergence of new connections where none existed. Secondly, scalar devices enable maintaining connections, and lastly, they also enable knowledge production. The second move by making this contribution is that it provides another lens that decenters personal connections.

In the second contribution, I draw to the question of what does scaling human infrastructure mean? This is important as it helps us understand what scaling specifically in human infrastructures is, unlike, say, computing infrastructures. Is scaling human infrastructures adding just another person to the project? Understanding this question is essential in understanding when we change scale, which brings us to the concept of scalability. As mentioned earlier, scaling human infrastructure is much more than just adding another person. There is a contextual, intensional seeking out for actors with access to specific scalar dispositions or scale of actions. Scaling here is not just about adding more people but rather how to add the right people.

In the next section, I highlight how scalar devices act as instruments for maintaining co-operation. I then show how they provide opportunities for the emergence of connections and lastly show how they act in knowledge production.

6.1 Scalar devices for sustaining co-operation

In this section, I demonstrate how scalar devices are essential in maintaining co-operation. They do this by enabling the collapse of either space or time and, in some cases, both. Collapse, as mentioned in the literature review, refers to the facilitation of ubiquity as a property. Additionally, they also help in the management of large multi-disciplinary teams. Several scholars within CSCW and STS have highlighted the role of personal connections in building infrastructures. Scholars such as Nardi highlight the role of shared history and emergence as how new relationships develop and are maintained. Within cyberinfrastructures, the question of sustaining co-operation is at the forefront, as highlighted by Bietz et al.(Bietz, Ferro and Lee, 2012). Bietz et al. argue that part of sustaining co-operation in infrastructures is through maintenance. However, what or how do human infrastructures sustain co-operation? Here, I use the notion of scalar devices as presented by Ribes to show how scalar devices could act as ways of sustaining co-operation. Ribes argues that by examining the enactment of scale, we can investigate diverse kinds of size and growth within social-technical systems. Scalar devices are useful instruments in helping us understand the scales such cyberinfrastructures define and use.

The SS project is not any different from any cyberinfrastructure out there. Cyberinfrastructures are a form of infrastructure that brings people, information, and technologies together with a research lens at the core. Cyberinfrastructures are highly technological, employing some of the latest advances in methods and technics. Examples of scholarship that describes different cyberinfrastructures include Lee et al.'s work on

brain imaging infrastructure from different sites(Lee, Dourish and Mark, 2006), Karasti's scholarship of the Long-Term Ecological Research Network at different sites(Karasti and Baker, 2004) and, Ribes's work on the GEON infrastructure supporting the geosciences network(Ribes, 2006). Cyberinfrastructures tackle large-scale research problems and take on a multi-disciplinary character, are highly distributed and, technologically centric. Such infrastructures span multiple scales at the same time.

However, unlike most cyberinfrastructure projects, the SS project is slightly different. It differs in that not only does it seek to find answers to challenging large-scale problems such as climate change and climatic downscaling, but it also active in engaging with different publics at a locality. In a sense, research is done outside the walls of labs or supercomputers and done 'out there' where differing local needs are aligned. In this project, several participants highlighted the contextual application of climate science in the 'real world.'

The team comprising of members located in different parts of the world meet every two weeks via an online web teleconference. The Thursday before the meeting, a meeting agenda is sent out covering different aspects of the project that team members need to discuss. Over the past year, I have been attending these weekly meetings taking notes diligently. When I joined the project, the weekly agenda would be compiled by Mike, who was among the first people in the project. As the project's scope increased, the project brought on board an administrative manager whose primary function was to manage projects, find funding, and carry out some operational functions.

I remember vividly attending my first bi-weekly meeting. I had already met the entire team by this point at a workshop hosted in Savannah. Mike added my email address to the project's mailing list hosted on the university's infrastructure at the workshop. Once added, I would "*receive all the updates*," he said. I got my first weekly agenda as my subscription to the mailing list established a communication channel. The email had a web conferencing URL that would synchronize with my digital calendar upon clicking the accept button. As the university pays for a subscription to the Blue Jeans web conferencing service, all I needed was to use my university address to attend the meeting. In any case, anyone with the unique Blue Jeans URL would be able to attend the call every second Friday at noon. The mailing list and the digital tools such as the web conferencing service act as scaling devices here, allowing for all project members at different sites to attend. Besides the collapse of space, the synchronizing of personal calendars is also essential, acting as a constant reminder of establishing project rhythms. These project rhythms then become translated into biological rhythms when members attend.

Nothing particularly stood out in my first conference call other than introducing myself as a developer working on the emergency dashboard that summer. However, after attending the bi-weekly meetings for more than a year, a couple of things stood out to me in retrospect. One is the increase in the scale of the project with time, which led to disappearing voices. As more and more people joined the project, there were fewer opportunities for some members to speak. An increase in the number of members for a

one-hour meeting with a set agenda made participation opportunities less frequent. The two co-PIs initially chaired most meetings; thus, the project hierarchy helped determine who gets the chance to speak. Mike was also in charge of running these meetings. However, more emblematic of a scalar increase other than an increase in the number of participants in the project is the loose formation of working groups where the group leader would speak on a focus area. For instance, teams such as the dashboard, the sensor installation, and the Maproom team would provide updates on what they had been working on since the last meeting. Groups are much more than just a loose amalgamation of participants. I argue that groups are also modules representing how one may organize human infrastructure to meet specific ends. A scalar increase here is not just through the increase in participant numbers but also through the contextualization of the project needs into groups responsible for them.

Communication between team members in such a cyberinfrastructure is essential. I interviewed Mike on the third day in March 2020, and he emphasized the role these tools, such as mailing lists, bi-weekly conference calls, meeting agenda, and post-meeting notes, play in organizing such work. His role within this project also enabled him to highlight this role communication plays. He stated, "*I think because of the remote nature of this project, we've had to invest pretty deliberately in communication. One of the outputs of that communication is to help adjust to the right scale and pull in the right people for what we are doing so we can accomplish our task.*" When I asked him to elaborate, he mentioned an anecdote where, while working on the project, there was a point where they needed elevation data. The county emergency department did not have

that data. However, by reaching out to the department of transportation and the county engineering department, they were able to get elevation data for the bridges. By the '*right scale*,' Mike refers to the state's department of transportation that operates at a larger scale and is considered the custodian for road and bridge data for some roads.

The scalar implications of working with the department of transportation are several. In a sense, road networks and bridges as infrastructure highlight the spatial and temporal fixes that become institutionalized at different scales. At the national level, the department of transportation works in tandem with local authorities in maintaining a national highway system. At the state or regional level, the state's department of transportation institutionalizes a network of roads and bridges that they claim ownership of while at the same time being bound by space and time. They are bound in space as they build and maintain part of an infrastructure that is limited by state boundaries and considered large-scale state arteries. Institutionalization entails building connections with participants in such institutions as they control and hold authority over specific sections of the infrastructure. Ribes and Finholt make a similar point on the institutionalization of infrastructures and the scale of institutionalization(Ribes and Finholt, 2007).

Another implication is the politics of scale at play. The state's department of transportation is bound to the state of Ventria politically. Political boundaries that constitute spatial imaginaries do the work of limiting the department's actions within the boundary lines. However, the scales of action are limited not just to the political boundaries but also to the spatial demarcations brought about by infrastructural

boundaries. Infrastructures inherently have a spatial-temporal fix(Harvey, 1981), thus presenting boundaries. Also, as different administrations belong to an electoral calendar in the political context, such rhythms influence such an agency's operations on the temporal scale.

By having such meetings where project members raise issues or needs, members can discuss and find approaches by working across scales. More importantly, it is the role bi-weekly meetings take as a scalar device that allows for a project such as this to synergize and synchronize as it is operationally part-remote. Scalar devices are essential as they help bring on board more people and help bring in the right people. Here is where I make a more nuanced argument on scaling where the situational context is vital in determining the right person. Part of scaling in the SS project entailed getting the right people, which was essential to obtain scale. This scaling entails a scalar strategy of making connections with the right people at different institutions who access different scalar operational frames. Also, as the project holds meetings through web-conferencing tools, members worldwide can attend as space and time collapse.

Scalar devices such as bi-weekly meetings sustain co-operation in several ways. In one, they act as sites of synergizing manifested through the ability of members to come together to provide project updates and identifying other partners who could join in. Explained differently, not only are the weekly meetings an accountability/informational mechanism, but also they act as mechanisms of resolving scalar conflicts. For instance, when Mike points out that there is the need to "*pull in the right people,*" it entails scaling

the team in number by finding the right person. The situational context of finding the right person is telling. Thus co-operation is initiated when finding the right person. However, it is also a tactical move in working across different scales. Through the provision of bi-weekly updates, project members can synergize with their colleagues on issues that arise. The formation of ad-hoc groups to apply for different grant opportunities is a good example. Bi-weekly meetings as scalar devices are opportunities where colleagues learn about each other's work and foster collaboration. As mentioned earlier, as the project team scaled up, a project manager was hired to manage the bi-weekly meetings. The new project manager was now the custodian of this scalar device. The scale at this stage takes a bio-form.

Another scalar device that sustains co-operation in the SS project is the workshops. It was in May 2019 when I attended my first workshop on short notice. The project held the workshop at the old city administration building. The building looked antiquated and empty. I learned that the city had considered the building unsafe due to structural weaknesses. Unlike this building and its weaknesses, workshops are essential as they bring about structure. The ability to meet in a room and collaborate on the project based on a common agenda shows how structuring facilitates co-operation. The building was also sinking as the city sits on some sections of reclaimed land. The city had cut off the water supply leaving the water fountains dry. Inside one of the large rooms sat the project team around a u-shaped formation. After a round of introductions, several project members made presentations on different aspects of the project. It was at this workshop

that I introduced myself in person to the other members. It is here that I first met Oliver, Henry, Ethan, and Alex(these names are pseudonyms).

Oliver was there as the West county's emergency manager, Henry as the city of Dosta's sustainability manager, and Alex representing OpenCity. OpenCity is a local non for profit that works to build civic open data tools. It is a local chapter of a national non for profit civic technology program. I will spend some time contextualizing the work of the non for profit and how the issues of collaboration could be reshaped due to higher-order scale effects later on. Most of the other members were from the university other than Ethan, who represented HH, a local public benefit organization. The workshops are a chance for team members to assemble, meet, and share progress updates and synergize. The physical holding of these workshops in Dosta in partner offices was by design, as this allows us to go into the spaces where partners work.

However, workshops were much more than scalar devices that facilitate collaboration amongst project members. They were also tools through which upper management keeps a tab on project progress. Here is where I argue that scalar devices act as instruments for growing in scale and essential in the management of scale. They play a dual role of acting as tools for maintaining collaboration but also as tools to manage and maintain the scale of the human infrastructure in consideration. In a sense, scalar devices sustain co-operation but are also useful in managing co-operation. Other than the workshop tracks organized, the project leadership also organized meetings with other local partners. The

team would capitalize on having most of the core project team members in the same place to meet partners.

Having all the leaders and members in the same place enabled schedules to be synchronized. The team would be able to see the mayor together(and other partners), presenting a team behind the project. Since attending my first workshop, the project has held all the other workshops at partner sites. The local UoD Dosta campus hosted the second workshop I attended. The third was at Dosta State, and the last one I attended before the pandemic was at Woodville high school. The holding of workshops in these sites enables more in-depth engagement with partners at these sites. For instance, holding the workshop at the school entailed liaising with the school administration to synchronize calendars and organize activities during the workshops. The workshops are also an opportunity for those who may not be heavily involved with the team to be more involved. In the first workshop, a local museum hosted an afternoon session, where the project made presentations to the general public. It is here where the previous mayor also got a chance to give his thoughts on the project. In the last workshop that I attended at the school, local students participated in an afternoon mapping exercise. Mike aptly summarized the significance of workshops when he stated that "*part of having meetings every other month in Dosta is to make sure in-person meetings are accomplished as members are split up between Dosta and Dublin.*" In addition, project partners situated in Dosta do not necessarily see each other; thus, facilitating such opportunities to meet all project members in the same room to calibrate and work towards common goals is vital.

He also added that the people who make the yes or no decisions need to be always in the loop and need to have sufficient ownership of the project.

As Mike points out, the physical hosting of the workshops in Dosta is based on shared principles. One is that workshops are sites of keeping participants "*in the loop*" and engaged. In a sense, workshops foster collaboration and maintain it. Moreover, workshops also act as tools for enacting ownership. Essentially, the ownership described in the SS project takes on a different frame. Unlike other models of ownership of infrastructures such as public versus private, or other models that position infrastructure as part of a commons, ownership is vital for the project's long-term sustainability. Other scholars have pointed to the role of local ownership in bringing environmental concerns to the center and engendering the public's participation in scientific research(Wiggins and Crowston, 2011; Sheppard *et al.*, 2017). Projects such as the One Laptop Per Child also argue for the role of ownership in maintenance(Rosner and Ames, 2014). In the SS project, several frames are present in enacting ownership. As a long-term project focusing on climate change, the site necessitates ownership as local partners have a "sense of place." Project partners also become owners as their work needs, specific tasks, and rhythms become embedded in the infrastructure. As a scientific research project, the project first meets the needs of the local partners through flood mitigation, STEM education, community engagement, and provides hyperlocal forecasts. By focusing on sustainability, the project addresses both the maintenance of the infrastructure and long-term climate change issues.

By fostering or inculcating ownership, project participants in Dosta and the larger West county can easily leverage other institutions and draw them into the project. As participants who have ownership of the project, the local partners can easily invite policy stakeholders, other city or county staff, or other institutions to the workshops to gain institutional buy-in. When I spoke with Doris, a member of the project team representing the Metropolitan Planning Commission (MPC), I remember she detailed how she became involved with the project. She mentioned that her boss at MPC got an invite to the workshop, but she forwarded the invite to her asking her to attend on her behalf as she could not attend. The physical location of the workshops in Dosta enables such close interactions. Were they not held locally, perhaps such opportunities for emergence would not easily occur. Doris additionally mentioned that she became more involved not only due to her role at the MPC but also due to her personal academic interests as she is interested in studying the heat island effect. This project presented an opportunity through which she could do such work. It provided a convergence of her work, her locality, and her interests. Ownership is crucial as it is also helpful in maintaining such cyberinfrastructures. Maintenance is present through the bio scale working through other scales. Embedding the human infrastructure into the new SS project allows for the project's long-term sustainability. Through regular meetings and other scalar devices such as workshops, members are engaged, and participation sustained. As the project is highly multi-disciplinary, bringing together different actors from different disciplines situated across the world, scalar devices are essential. They help not only collapse space and time through digital tools but also enable operation across different scales. It is

because of scalar devices such as workshops that allow us to understand the different constructions of scale and how to work across them.

In this section, I demonstrate how scalar devices are essential in maintaining co-operation when scaling human infrastructure. Through the bi-weekly online meetings, team members are able to meet and update each other on progress made. The ubiquity due to the collapse of space and time allows for team members in different locations to synergize and organize towards project goals. In this frame, scaling takes on a geographic reach framing as participants attend from across the world. Another frame enabled by the online meetings is the scaling discourse brought about by adding the "right people." In this frame, scaling is not just the addition of another participant but the situational context around adding the right people. The right person is contextually defined as they enable a change in scale bringing with them access to scalar operations or strategies. Unlike bi-weekly meetings, workshops are different in that rather than collapse space and time, participants are in the same space at the same time, colocation. The socio-materiality workshops bring about are remarkably different. The physical presence of holding workshops does much more than maintaining collaboration. Colocation also fosters a sense of ownership for the project participants. The planning involved in hosting a workshop entails much more than the physical planning and hosting of the event. It is much more than reserving a room, organizing lunches, and inviting people to attend. Tactically, it is also about project members letting their institutions be 'in the loop' and engaged by especially drawing in upper management in some of these partner institutions. Workshops also enable people in different institutions to attend meetings

locally as they may not be able to attend the bi-weekly meetings. In instances where upper management cannot attend, the project team would organize to meet them and make presentations to them. For instance, the project team members going down to city hall to meet the mayor or the city board. These meetings were only possible due to the colocation of project team members in Dosta.

6.2 Scalar Devices as tools to initiate co-operation

In this section, I highlight how scalar devices also act as tools that bring about co-operation. Several scholars with STS and CSCW have highlighted the role of personal connections in growing human infrastructures(Lee, Dourish and Mark, 2006). However, as mentioned earlier, personal connections do not fully account for how co-operation is initiated or comes about. By their nature, I argue that scalar devices are another lens through which the initiation of co-operation occurs. More specifically, I draw on the notion of emergence as defined by Nardi et al. that refers to networks that are "called into existence to accomplish some particular work(Nardi, Whittaker and Schwarz, 2002)." I illustrate how scalar devices in the form of *outreach* and STEM education are tactically employed to bring about new relationships into the network, especially when personal connections do not exist. Both forms highlight how unintended and unplanned connections are established and foster co-operation leading to scaling.

The term outreach came to my attention when I interviewed Dr. Davis at one of UoD's buildings. He began by explaining how the project came to be when he mentioned that it all began as he was doing outreach. He mentioned that the project has not only relied on

personal connections but has entailed '*meeting people one after another.*' When I asked him how this entire project began, he stated. "*Basically as outreach for UoD, Dosta. Rotary meetings, community things. And I started basically adding to my stump speech, if you will, the story of Irma and Katrina, I mean Irma and Matthew, not Katrina.*" What stood out to me with my advisor was how this project came to materialize. As Dr. Davis is based in Dosta and given his personal experience in Dosta, the initial events that lead to the project materializing were by doing outreach. Through outreach, Dr. Davis is able to attend local meetings enabling new relationships to emerge. As he stated, some of the meetings included making presentations to Rotary clubs and attending other local community events. When we asked him what his "*stump speech*" was about, he mentioned that the speech was generic and mainly focused on the Internet of Things (IoT).

During this stump speech, he talked about IoT and how the city could use it for things such as light management, parking management, trash cans, among other things. The speech was generic, and at this point, the scope and area of interest in the project are undefined. Non-existent as a matter of fact. It is telling, though, that a generic presentation materialized to a specific infrastructural intervention of a sea-level sensing network. When pitched to a public audience, the project was not concrete, but rather the presentation provided several possibilities. In a general sense, the presentation indicates the technology is scalable in that IoT is deployable for differing functions. The generalizations on technological use are also tactical as it enables a broader scope and reaches more potential partners.

However, it was also because he lives in Dosta that he could draw in the audience to something they all commonly experience. Other than the examples provided above, he also surfaced the poor visibility or information deficiency problem, especially after hurricane Irma and Mathew. His calculated use of the two hurricanes to invoke interest based on his personal experience as a resident was significant. The problem of poor visibility and how the area was affected by hurricanes prominences shared experiences. The challenge of visibility is what he would leave with their audiences as he stated, "*I would just kind of leave that as my challenge for them. Just hoping something would stick.*" After his speech to the attendees, one of the participants approached him and said that he would connect him to Oliver from the West(county) emergency management agency. Dr. Davis gave him his business card, and eventually, both Dr. Davis and Oliver were connected.

When I sat down with Oliver to ask him how the project came to be, he mentioned that a participant who is a realtor attended the outreach event and approached him. He mentioned that he met the realtor at a flood mitigation meeting who spoke about this '*guy from UoD*.' Oliver reached out to Dr. Davis, and the rest they say is history. Somehow, a realtor interested in flood insurance was able to see the utility of the technology, thus linking Oliver to Dr. Davis. The multi-scalar implications abound in different forms. For instance, local households have to purchase flood insurance if they sit in flood risk zones in the economic frame. Another scalar frame is at the federal level, where the Federal Emergency Management Agency is involved in producing flood risk maps that determine

risk and useful in insurance underwriting. Local city administrators enforce building codes and issue permits at the local level, including building elevation profiles to manage planning in flood risk areas.

As a scalar device, outreach enables the rise of new connections. For emergence to occur, several things were in alignment in this case. Dr. Davis making his speech as part of outreach is one way he can scale. The description of a stump speech is to draw others into an allyship by piquing others' interests. Through events such as outreach, Dr. Davis is able to draw new partners into projects that they could collaborate on. Though others may have divergent motivations, the actual act of carrying out outreach work entails a form of enacting scaling. In sum, it is an act of infrastructural becoming where the exploration of possible research directions occurs, pivots established, alignments and realignments occurring. Outreach is also political in that it entails the active act of extending outwards, therefore invoking an extension. The active preparation of a 'stump speech' is political seeking to influence other actors. When discussing scale in the context of reach and scope, outreach entails moving beyond the current limits or conditions. It entails an extension of some form.

However, Dr. Davis's experience in Dosta was also essential as he could draw upon that shared experience with others at such outreach events. The use of extreme weather events such as Irma and Mathew are illustrative of how outreach also has to cater to an audience. Outreach fundamentally entails team members making an effort to go to events or other spaces where establishing connections is central. Part of this process of outreach

is positioning something as '*why should this matter to you?*' It is an event that seeks to draw people in to engage. Contextualizing outreach with things that matter at the local is also essential. In a sense, outreach work entails a form of localization but also a process of scaling.

Outreach is also situationally different based on the perspective of the actors involved. For Dr. Davis, outreach entailed going out and speaking at events about IoT. Rather than a scalar device deployed by team members, outreach can also be in the form of meetings where project team members attend and make new acquaintances. To clarify, other forms of outreach organized by other convenors also act as scaling devices. Take the case of how Dr. Smith and Dr. Davis met and got involved in the project. Dr. Smith mentioned that they met at a UoD smart cities grant briefing as she was seated right next to Dr. Davis. This happenstance enabled them to discuss climate change, sea-level rise, and flooding issues in Dosta. Due to this chance event, co-operation commenced as Dr. Smith joined the project by applying for the grant together. In this case, the university's event was a scalar device enabling two participants to meet.

Others, such as Oliver, have other perspectives on outreach. Outreach is not just about bringing partners and others into the sea level sensor project. The engagement with the public through digital tools is a form of outreach. Oliver emphasized this point by mentioning that digital tools such as the dashboard and the modeling accompanying it "*have great outreach components as hopefully they could drive the point home that hurricanes are dangerous.*" In this specific case, he referred to the scenarios and

simulation models that reveal the level of flooding in specific conditions. Though Oliver does not highlight how dashboards as outreach tools can bring about emergence to the project or bring about new connections, he points to the dashboard as an informational gateway that brings about co-operation with emergency officers. By providing accurate information through digital tools, the public is made more acutely aware of the oncoming risks and perhaps more likely to co-operate with emergency teams in the event of an evacuation. In this perspective, outreach is extending spatial and temporal scales through the provision of up-to-date relevant information.

Another scalar device I highlight uniquely different from outreach is Science, Technology, Engineering, and Mathematics (STEM) education. STEM education is implicitly political since its introduction points to a policy change or direction towards an interdisciplinary and applied approach. Its use also points to common views of deficiencies in current education policy. In some schools, STEM education is seen as a political curriculum choice to make students competitive in the labor market. In the SS project, STEM education takes on different forms as a scalar device. In the SS project, it is a mechanism through which the team is able to synergize and align several aims, unlike outreach. The scalar implications STEM education comes with are wider-reaching and more complex.

STEM education helps the team align the production of sensing kits to applied STEM education at a basic level. The team is able to quickly scale as it can now produce more sensing kits due to an increased labor pool. In return, students learn some soldering basics

and basic applied environmental sensing. The project teaches students how to build the electronic kits that are then deployed as part of the sensing network and also follow a custom curriculum developed by the project. Besides learning about basic electronics, the project engages with teachers to teach climate change and the risks associated with climate change. At the initial stages of the project, the project did not have a STEM component. However, the team incorporated the component after collaboration with UoD's STEM program. As the project scaled, the need to add a STEM component became more apparent as the project was working to figure out how to engage the public.

The multi-scalar operations STEM education enables by aligning different objectives are essential to highlight. In the context of public engagement, STEM education is a scalar multiplier in different ways. Positioning STEM education as part of civic engagement is tactical, especially as some see both as divergent. Some see civic engagement in elementary education as something that sits in the humanities and perhaps irrelevant. Other scholars have positioned this debate as a false dichotomy between STEM and humanities(Hartzell, 2017; Light and Rama, 2019). Due to this debate, some have advocated for turning STEM into STEAM with the A standing for the Arts(Boy, 2013; Radziwill, Benton and Moellers, 2015). The funding of STEM has also increased with every passing year. However, in the SS project, civic engagement is made possible as students make sensing kits to help the city and the county build out the infrastructure. They help the project scale-out and scale-up. They are civic participants as they not only learn science and engineering basics but also participate locally. They are also acting globally, I argue.

Local participation is vital as it signals a sense of ownership and also enables the initiation of co-operation. Students involved in the assembly of the environmental sensing kits would leave markings once they assembled the kits. Some would leave their names on the kit's outer shell, while others would write their initials or leave other markings, signaling a sense of ownership. Once the project team performed a quality check on kits assembled by the students, they were installed and added to the network. The sense of ownership has a lubricating effect, especially when dealing with co-operation. As parents heard about the program from their children, some parents were happy with their involvement with the initiative. This parental support due to the STEM education means the project has the support of the students and parents who wield some power in their school districts.

The STEM intervention has also resulted in scaling challenges as schools are now competing to have the program in their respective schools. Dr. Davis pointed to the role STEM education has played in initiating co-operation. Because of the successful exercise with one school, several other schools became interested, including some that were initially skeptical of the initiative. Dr. Davis further explained: "That's *how I heard about this project is because the school system and now the school board chair and the school system is getting good PR out of it. We're helping them look good.*" As mentioned earlier, this contrasts with the installation of gateways (chapter on the spatial scale), as working on using schools as sites to scale the network seemed to run aground. However, in this case, STEM education had an opposite effect where one school's experience unlocked

opportunities at other sites and brought about emergence. Also, the positioning of "*looking good*" is vital as it positions STEM as a unique value proposition. A proposition that allows for better-prepared students with skills that are necessary for the future. A temporal scaling occurs.

Through an educational policy lens, STEM education is seen by many as of immense value. The increasing funding available to STEM initiatives points to the scalar effects brought about by such programs. This flux of funding has also resulted in significant changes at the school scale and educational district scale. Building STEM curriculums, teaching STEM courses, and the involvement of school districts and elected school officials in managing such programs points to the different scalar dimensions STEM education tackles. In the case of the SS project, the project built a custom curriculum based on other similar initiatives carried out in other places. The project team also held a teacher of teachers training as this enables the scaling up of STEM education. Importantly is also the value placed on STEM education. Due to the ubiquity of digital systems, many view this form of education as necessary for success in the future. However, at the national level in the United States, this turn becomes clearer due to the view that there is a shortage of science and engineering graduates in the workforce(Hoshizaki, 2019). Other scholars have highlighted this shortage as a myth(Charette, 2013; Stevenson, 2014). Science and engineering occupations position one at the leading edge economically in a competitive globalized world. Therefore, the turn towards STEM is also an explicit turn to be globally competitive. At the local level, STEM education enables the marshaling of synergies where the project is able to gain

funding from educational sources, local schools benefit as parents, and local administrations are happy. On the other hand, students learn skills that are touted as necessary for being competitive in a future global marketplace helping the country to be economically competitive.

The role STEM plays in skill-building and taking an oversized role was not crystalized until meeting Dosta city officials. As mentioned earlier in the section on space and scale, I was seated in the meeting taking notes. On that humid morning, a lady walked into the meeting late. She was the Alderman for one of the districts. Dosta's city governance system is unique as local elected officials for electoral districts are called '*Aldermen*.' As Dr. Smith was giving the presentation, she took a break as the city manager interjected to welcome the Alderwoman. After offering her apologies and doing another round of introductions around the room, Dr. Smith continued making her presentation. It was not until Dr. Smith got to the STEM component in her slides that the city manager interjected to explain to the Alderwoman about the project's involvement with schools. He explained to her that local school children were involved in assembling some of the kits. Her eyes lit up wide open as Dr. Davis handed her one of the kits assembled by the students.

Meanwhile, Dr. Davis explained to her the markings on the kit and stickers placed by the school children who assembled the kits. Henry added the importance of involving kids in translating short-term flood management to long term infrastructural planning. She deeply paused, seemingly in deep thought, and asked, *"with this development, research with UoD, whose idea was this?"* A collective pause engulfed the room for a

second or two, and Dr. Davis explained that everyone at that table and others outside the room were responsible for getting the idea implemented. Once Dr. Davis completed his statement, Henry interjected, restating the challenge of flooding and the low visibility issue due to the one sensor at Fort. Norad and mentioning the uniqueness of the project. "*So, we are the leaders in this*," she responded. Several members at the table in unison let out a collective yes, Henry picking up the mantle to explain how unique the project is also at a global level.

The discourse with the Alderwoman when she posed the question on the idea's origins tell us more about the context of this as a scalar device. In one frame, it is a question of how the idea came to be concrete at this site. In another frame, it represents a curiosity of how something like this would attend to the different sensibilities in Dosta. As a scalar device, the kit was not only useful in environmental sensing, but it also takes on several other roles, such as acting as a base for a STEM education of kids in public schools from an underserved community. Though such communities may not be as acutely aware of climate change issues, STEM education provides a pathway for them to develop deep connections with the project.

Despite holding meetings with different actors on the political scale, scalar devices could elude local leadership. Through scalar devices such as outreach and STEM education, the scalar gains through such operations make it easier to have discourse with those who operate at the political scale. The scale of operation of UoD and its standing also has helped build momentum to bring onboard other partners and collaborators at the

political scale. The framing about being leaders in this specific form of environmental sensing also illustrates how others see global competitiveness on the political scale. In this form, it is not only through opportunities to those at the local level but also a site that is seen to have an infrastructure, unlike any other globally. In economics, the term first mover advantage highlights the unique position those who lead are able to take advantage of.

At the end of the meeting, the Alderwoman stated something that I found very instructive in hindsight. At the tail end of the meeting, as Dr. Brian had just finished his presentation, she started by saying that she would not say more. However, as she picked up the sensing kit in front of her, she explained about the young people of Dosta, stating that at one time, all of us in that room as science professionals were kids, but what was most important was the opportunity. The opportunity for kids in high school to "*lay their hands on this"* provides an opportunity that will change their lives and thought patterns, thus bringing innovation to our lives and their future. The opportunity would enable our young people to make easy decisions to go to UoD and become science professionals. The position of STEM education as an instrument of opportunity is telling, especially the multi-scalar implications of such an education.

However, in the context of this section, I want to highlight the role that STEM education plays as a scalar device that initiates co-operation. Yes, it does much more than initiate co-operation, but it is due to its perceived value that it enables that co-operation. Here is where it is crucial to understand positionality in relation to the different frames of

its scales of operation. As a project component, it helps in initiating co-operation and enlisting political support. In addition, it also unlocks other funding sources the project could be eligible for. To a school, it helps the school stand out in the district as education administrators gain good "*PR*." It is an opportunity creator for the local political class and makes the local site competitive on the world stage. On a national scale, it is part of the political discourse on educational policy. The enlisting and the alignment of needs and synergies through this scalar device has a force multiplier effect, unlike outreach.

As a tool, gaining momentum with the rest of the city administration was made easier through scalar devices such as STEM education. At one point during the meeting, she asked if the city granted the team access to the lift stations. For someone engaging with the project for the first time, she intuitively knew that access to the lift stations was essential. She was not in the meeting when Dr. Davis had spoken about them, but somehow, she understood how that access would be beneficial to the project. The city manager interjected to state that they just had that conversation and would follow up on the access issue. In addition to asking about lift stations, she also asked about schools in her district and mentioned that she would follow up with some to get them involved.

In conclusion, STEM education as a scalar device stands out due to the ability to have it employed at several scales simultaneously. At the project level, STEM education helps scale up the production of sensing kits. Though the project team would be sufficiently able to assemble the kits themselves, the involvement of school-going children is a scaling tactic. It is this situational context that I highlight as important when talking about

scaling up human infrastructure. The involvement of school-going children entails a form of temporal scaling. Children learn the basics of science, engineering, environmental sensing, and climate change in the immediate present. These skills are seeing as ways to get them excited about careers in STEM fields in the future. Also, in the future, as they will have to deal with issues of climate change, this education is seen as equipping them with the tools for living on a planet at risk of environmental catastrophes. At a national level, this training acts as a way to bridge the mythical gap or deficit of STEM graduates in the workplace. On a global level, some view a STEM certification as globally competitive. Thus, local sites such as Dosta seek to be competitive as some see this as likely to draw better opportunities.

For the project itself, STEM education also acts as a scalar device in that it entails enlisting schools. Due to the competition between schools themselves to offer this kind of education due to the hype around STEM, several other schools reached out to become more involved. At a school district level and political scale level, local administrators were eager to get their schools involved in the program and, in turn, helping the project scale the physical network. The political scales are also important as they understand public infrastructure and systems well, knowing who to reach out to, and following up with local administrators.

6.3 Scalar Devices and Knowledge Infrastructures

As defined by Edwards(Edwards, 2010), knowledge infrastructures are “robust networks of people, artifacts, and institutions that generate, share, and maintain specific

knowledge about the human and natural worlds." For Edwards, knowledge infrastructures aim to capture routine knowledge systems. Similar to the global weather knowledge infrastructure, so too is the sea level sensor project, albeit at a different scale. The global knowledge infrastructure for the production of knowledge on climate change is composed of several constituent parts. For instance, the network of data sources from satellites, buoys, planes in flight, ground weather stations, among many others, illustrates a greater diversity in data than the SS project that utilizes data from local DIY sensors, local authorities, and Fort Norad. The scale of the data collection in the knowledge infrastructure is larger than that of the SS project. Also, the scale of expertise in that infrastructure is grander, consisting of glaciologists, earth, and atmospheric experts in marine, air, and land. In contrast, in the SS project, the pool of expertise is not as extensive. For instance, there are no glaciologists present on the team.

This section focuses on how infrastructural development, such as the SS project, relies on processes or routines of knowledge infrastructures to scale. In the context of scalar devices as instruments for scaling the sea level sensor project, an increase in scale is much more than just an increase in numbers or co-operation. Scaling entails a situational context of adding and enlisting the right actors or entities that have access to specific scalar operations.

An example of a scalar device part of some knowledge infrastructures present in the SS project is the role grants play. Grants are an instrument that enables the scaling of the project and the human infrastructure in specific. Within the sea level sensor project, I

view grants as fulfilling two forms of scaling. One form of scaling grants facilitate is technical in that they finance the development of the project's technical aspects. Initial funding from UoD through a "Smart Communities" grant enabled the project to purchase the materials needed to build out the network. The scale here involved moving from no sensing kits to over twenty sensing kits and the supporting infrastructure(gateways). The grant at the initial stage involved building a proof-of-concept centering on the actual hardware. As part of building a proof of concept, the team tried different sonar sensors, bought a professional sonar sensor for calibration, and designed the outer casing for the sensor kit, among other tasks. As Henry mentioned in the interview that when he said, "*he would be interested*" in the project, at that point, "*he didn't know that anyone had a sense of how far this thing was going to go.*" He added that it was "*a small grant and that it was kind of an inaugural grant*." Oliver also mentioned how vital the grant was to enable the project to start as they had some funds to do a proof of concept. The grant allowed for scaling in that it fostered the development of sensing units, thus increasing the number of kits, but also used in scaling the network in the spatial sense through physical installation on bridges and the installation of gateways. The project also scaled up on the temporal scale as the initial objectives become bigger and bolder with time. What started as a simple sensing project expanded into sensing air-quality, providing STEM education, among other things. The project does not just scale up in the number and geographic distribution of hardware, but also in the temporal. In this technical scaling form, the human infrastructure scales as grants facilitate the collaboration. Without the grant for the technical, the human infrastructure that is embedded lacks a place to sit on.

The second form of scaling is grants allow for the realignment, reorchestration, and incorporating other perspectives not present at the project's onset. Researching entails an in the making process similar to infrastructuring(Karasti, 2014). As mentioned earlier, infrastructuring entails a process of becoming(Karasti, 2014). Take the case of the STEM education component, which was not present at the onset. The incorporation of STEM was also to enable the project to leverage grant opportunities within UoD for STEM funding. This incorporation is an act of leveraging and aligning UoD's STEM initiatives with the project's needs. The ability to leverage other departments within UoD gives the project a greater scale as the possibilities or opportunities for additional funding sources increase.

In a sense, my central position here to clarify is that grants help projects scale in a more straightforward form. In this form, project teams apply for grants as they need to scale, moving from research questions to undertaking research work. In the case of the SS project, scaling is from a series of local problems that require an infrastructure that occupy dimensions of space of time. Thus, it is not only the initiation of a research agenda but also the development of infrastructure. In this case, the project's initial intentions or goals are intact, and the goal of grants as a scalar device is to initiate the project from nothing.

However, the reality of research projects is that plans, and techniques may change. Here is where I make a more nuanced argument that grants also frame research projects. Grants also force researchers to think about how their work is scalable in their field and

how their work scales to other dimensions to meet funding calls and requirements. There is a need for political malleability on the part of researchers as they seek funding for their project. It is this positioning that grants function as scalar devices also.

However, STEM education grants are not the only tactic that the project utilizes. Since I joined the program in May 2019, the number of faculty investigators has increased. More faculty members have come on board the project with specific perspectives from their relevant disciplines. In a sense, by bringing on board more faculty, the research scale also increases. By scaling here, the number of research contributors increases, and the expertise and other disciplinary scales become incorporated. I will highlight the matter of disciplinary scales later. In a multi-disciplinary team such as this, as faculty operate at different scales, different scales are reflected in the project.

The increase in faculty investigators also plays a role in the grant application process. As an outsider looking in, seeing a highly multi-disciplinary and accomplished faculty plays an outsized role. With an increase in the number of experts and faculty, the Smart Sea Level Sensor project's human infrastructure scale is greater. The SS project's scale is not only framed in the context of an increase in faculty but also impact. Here is where scaling also entails a contextual increase of the right people and not just a simple increase in participants. These are factors that grant applicants consider as the team of principal and non-principal investigators on a grant application matter. The composition of investigators and partners plays an essential role in scaling such projects. It may be

because of a grant application that some partners or faculty join in, thus increasing in scale as the probability of getting the grant is higher.

This process of incorporating new scholars or investigators into the team involves drawing up further research questions or, in some cases drawing upon the grant's call to tease out additional expertise needed. Thus, grants play a dual role—one as funnels to bring in knowledge and in the second as framing research. In the sea level sensor project, Dr. Smith highlights how the grant played this dual role. As the "Smart Communities Challenge" needed grant applicants to work with a community partner, both she and Dr. Davis had reached out to Oliver independently to bring him on board as the community partner. They then decided to loop in the City of Dosta and applied for the original grant as the leading four partners after adding Henry.

Grants play a role in knowledge production in scientific work. Other scholars have highlighted the role that grants do in directing the kind of research that is carried out(Lave, Mirowski and Randalls, 2010). Even large research projects, such as the Manhattan project, are intrinsically linked to other multi-scalar effects and implications. As an example, the GI bill passed as a democratization of education provided fellowships integrated into grant structures and insisted on the open distribution of the results(Asner, 2004; Lave, Mirowski and Randalls, 2010). At the local level or individual level, students joined universities as part of the war effort. The cold war in itself was global in nature. At the regional and state-level, educational institutions were part of the initiative through the production of knowledge. However, with the reduction and cuts to funding to education,

especially in higher education, external granting organizations now play a significant role in driving research rather than researchers driving the research themselves.

In the SS grants, PIs view openness as crucial as it unlocks collaboration and co-operation. As Dr. Smith added, that in science, "*we don't compete with each other to reinvent wheels and see who can get there first*." This approach is what makes science great, with openness at the core, enabling collaboration and capacity building. Scholars such as Bietz et al. also highlight openness as a value within cyberinfrastructures(Bietz, Ferro and Lee, 2012). Openness enables scientists to marshal their collective skills and funding to work on exciting research questions. Also, specific components of such large-scale projects make it easier to initiate collaboration. I am reminded of when I sat with Dr. Davis when he described to me when he and Dr. Brian went to North County at the Naval base, where he went to pitch the project to them. As he was making this pitch to people in the military, he did not expect one of the leads to mention that they liked the project. The leader further told them that they wanted to support the project and make the grant proposal happen, but they specifically also wanted the high school system involved. "*We also want that piece of it*," is what the leader stated.

As scalar devices in the specific case mentioned above, grants act as a tool to bridge two human infrastructures operating at different scales with differing values. In the SS project, working with various political scales is part of the process of scaling the infrastructure. The context for seeking collaboration with the military was through a cybersecurity grant where the position put forth by the team focused on the resilience of

digital technologies relating to disasters and climate change. The realigning of the project along the lines of a cybersecurity issue highlights the scaling work that researchers have to do to be able to obtain funding. Also, as the scale of the funding is considered large, more than half a million US dollars, researchers are willing to be malleable as more funding enables both temporal and spatial scaling. Conversely, the military grants are also a scalar device as they allow scaling by funding more infrastructural development. As potential participants in the project, the military's interest in the high school system points to a temporal scaling that provides for their sustainability through recruiting.

However, unlike researchers' malleability when seeking out grants to scale out their projects, social networking sites (SNS) are another form of a scalar device useful in scaling human infrastructure. SNS are digital platforms representing connections of interest as a network allowing users to have a digital representation of their network. This network may be grounded in actual physical relationships or grounded in areas of mutual interest. Several scholars, such as Castells and Tufekci, highlight the role of digital networks in social movements(Castells, 2009; Tufekci, 2017). However, there exists a lacuna in the role of SNS in knowledge production, specifically linking producers and how connections lead to research collaborations or direct research agenda. Other scholars have highlighted the role of such sites that specifically target academics, such as the citation service Mendeley or Academia.edu(Jordan, 2014). Others have focused on SNS and their role in academic career progression(Donelan, 2016).

In the SS project, Dr. Brian provided an example of how the popular SNS Twitter came in handy. Dr. Brian provided a perfect case of how knowledge producers at times may not know something, and as reaching out to each of their personal connections may be a lot of work, an alternative is to send out a blast on their SNS accounts. He stated: "*Nowadays I do it differently, though. Nowadays, I put an ad on Twitter.*" By posting the ad on Twitter, he refers to sending out a Tweet to the network of academics who are in his extended network about something he needs or is unclear about. As an academic, this is an experience that I am acutely aware of. It is common to see other academics pose questions or ask for help or direction on work that they may be interested in. Through such threads of discourse, academics may be able to focus on other areas of study. In this form, such sites become tools that direct research in a sense. When I asked Dr. Brian what he was looking for, he stated that he was "*looking for a sediment model.*"

Based on the collected sensor data, he realized that he was not sure about water movement in the marshes and the rivers and how sediment movement affects his local model. Complications arise, especially at the point where the rivers drain into the ocean as sediment is an essential factor at such sites, given the movement of tidal waves and the flow of the river in the opposite direction. He continued: "*and so what I did is I posted it on Twitter to all my network. I said, 'Can someone connect me to a sediment model?' And in no time, I had like five to ten names of people that I could interact with. So, it's a new world.*" The framing of his approach as a "*new world*" speaks to how SNS sites borrowing from a postcolonial critique could be as a form of territorial expansion. This form of growth is characteristic of digital systems as digital systems are instruments for

achieving infinite scaling. In the literature review, I have mentioned the viewpoint that commonly characterizes digital forms as being "*anywhere and everywhere.*" In the context of scaling the human infrastructure, such sites enable the connection of possible collaborators.

More importantly, is how scaling is present in SNS. As digital artifacts, they function as instruments that allow for global spatial territorialization. As mentioned earlier (literature review), the rhetoric of "deploy once, run everywhere" points to this territorialization. Thus, enlisting on an SNS entails developing a digital persona that is transboundary. On the temporal scale, SNS also become part of our rhythms, becoming embedded into our biological rhythms and routines. In the literature review on temporal scales, I highlight the concept of digital time and how "plastic time," as an example, accounts for those moments when an activity can be interrupted(Rattenbury, Nafus and Anderson, 2008; Irani, Jeffries and Knight, 2010). Also, as Lindley highlights, is the role such sites have in providing a sense of "nowness(Lindley, 2015)." Therefore, such digital sites enable a scaling where there is a spatial and temporal speeding up. In the spatial, one can reach a global audience at the same time. On the temporal, things that would take a long time, such as reaching out to the audience individually, are reduced to a moment.

The reterritorialization of space and the speeding up of time is not unique to SNS. These characteristics are mainly due to the digital form and nature of such networking sites. However, what SNS do are two things that many other digital systems do not do. One is the representation of physical and real-world connections as a digital network.

Even the language of such sites is remarkably different, pointing to establishing personal relations as part of a network. Language such as “following,” “add friend” are indicative of building the network. Terms such as “like,” “comment,” “subscribe” are forms of engaging actors in that network and entail sustaining connections with your network. In the context of building the network, a person’s reach is increased not just spatially and temporally but also numerically.

It is important here also to highlight how numerical scaling holds weight, especially in academic circles. SNS enables the emergence of connections due to mutual interests. Here is where it is also more useful as a scalar device as all users’ relations are abstracted and digitally represented, enabling one to tap into the network of their nth-order connections. By this, I mean that having my network and my friends’ network digitally represented enables me to tap into my friends’ network, including their interests. This way, SNS helps to scale in that such infrastructures makes it possible for one to rely not just on your connections but also on your connections’ networks. This representation results in having a greater network scale as one can rely on my friends/follower’s networks. In academic circles, SNS help one find the right people to connect with, especially when looking for collaborators. For Dr. Brian, both his network and his network’s connections were essential for scaling his research and making the linkages possible.

Conferences, unlike grants and SNS, are also scalar devices that utilize a different form of scaling. Unlike grants that seek an expansion of a different kind or SNS that are

also expansionary, conferences enable scaling from large to smaller scales. In knowledge infrastructures, they allow one to fit all the experts and practitioners in one room. In a sense, all practitioners traverse the globe to settle in one hotel room or university to discuss matters pertaining to their area of practice. On the spatial front, expertise is concentrated for that moment in a room at a place. On the temporal, rhythms become aligned during a specific set period following a predefined agenda. Conferences are unique as membership is not allowed to everyone even though the rhetoric around such may indicate that they are open. Conference attendance, for example, is an example of how openness as a term is in flux. Attendance may not be free as one may have to part with some money to participate. Also, a call for proposal explicitly limits participants that could attend as academic audiences are created and sustained. In some cases, remote participation is not permissible. Thus, even though the conference may be described as open, terms and conditions apply.

As sites where academics share ideas and collaborate, conferences are sites where project initiation may occur, new partners recruited, or where knowledge communities sustain collaboration. As in-person attendance occurs in most conferences, conferences reduce the spatial-temporal scales to a specific place and a particular duration. Attendees attend from all locations across the world to meet at a common site to follow a set meeting schedule. One could say that the human infrastructure in knowledge production is “downscaled” into a conference. The role of conferences became more apparent to me when I interviewed Dr. Smith in her office.

That afternoon, I walked into the new university building for sustainable design to interview her. This new building had just been completed and hailed as being sustainable. The entire building, also known as the living building, is a building built with the desire to be in harmony with nature. At the front, the wooden facade makes for a grand entrance with plants adorning the gardens at the front. Walking through the door is a series of bins with different recycling options and a trash can at one end. The building glass facade in some sections allows for natural lighting reducing the building's energy use. She had just moved into this office a few weeks earlier. The move into this office is not coincidental. The building acts as a form of sustainability in practice, thus also political.

During the interview, she mentioned that she was working on a conference that would bring researchers from different parts of the Eastern seaboard. She stated: "Castle University *and UoD are co-sponsoring a regional scale workshop that will pull researchers from New York City, actually, from Massachusetts, all the way down to Florida, up to DC for a two-day workshop on high-resolution sensors and modeling for coastal flooding.*" As someone who had been sitting in the bi-weekly calls, I knew the conference she was organizing. The meeting was bringing different scholars who use high-resolution sensors and study coastal atmospheric systems. The event's target audience was scholars whose focus area lies in the Eastern seaboard of the United States. The conference's organization and the conference itself are scalar devices bringing people with shared interests to DC to speak about coastal flooding on the East coast. By organizing the meet, the team can scale-out, reaching more academics interested in

partnering or collaborating. As a scalar device itself, the conference assembles all practitioners into one room.

However, the organization of this conference has other scalar entanglements. Specifically, focusing on the Eastern seaboard means defining a scale. As a scale, the geographic boundaries define who could participate. For instance, an expert on pacific flooding may not fit. Though the project did not make it explicit to leave out participants interested in replicating this work on the West coast, the scalar focus carries some implications. Besides, perhaps more important is the definition of a new research scale. Within earth and atmospheric sciences, this is not unusual. Climatologists regularly work with scale, and scales of interest define expertise. For instance, a climatologist may be an expert on the climatic patterns of the Pacific Ocean. Another may be an expert on historical climatology that focuses on human history; thus, the temporal scale is laser-focused on man's history. The hosting of the conference by the project team defines a new research scale that constitutes the United States' East Coast. By sharing knowledge and expertise on the East coast scale, the establishing of new knowledge trajectories begins. I argue that this turn is part of scaling the human infrastructure by focusing on knowledge production and sharing expertise.

Conferences as scalar devices allow for such scalar work. In one way, they bring expertise across the world to a place at the same time but also have scalar workings by defining scales of interest and in defining a social scale. For the SS project, the demarcation of a research scale is also a scaling tactic. Unlike workshops, they are

unique, as they entail a sense of disciplinary boundaries and sharing of academic work. As scalar devices, they seek to recruit knowledge expertise and define new research directions. Workshops are sites of multi-disciplinary operations where the scales accessible at a workshop are varied. There is a sense of active engagement with all participants in project planning and execution.

The scaling made possible by conferences as a scaling device is similar to that of outreach and workshops. When used to change scale, all three forms entail the convergence of human infrastructure in the same place at the same time. Co-presence and co-location on the spatial scale unlock other scalar possibilities and scaling strategies. On matters temporal, being in the same local time enables the establishment of personal connections useful in building and maintaining those connections. However, conferences are uniquely different from outreach and workshops. Conferences are highly situational exercises in knowledge production and sharing, unlike workshops and outreach. The openness present in these three demonstrates how audiences also shape what is considered open.

In this chapter, I have sought to answer two main questions. The first question I ask is, what does it mean to scale a human infrastructure? The second question I also answer is, how does one scale a human infrastructure. In the context of infrastructure studies scaling is framed in four common ways. In one way, it refers to a numerical increase. An increase in memory, compute cycles, or other forms. In another, it refers to a territorialization in the spatial layout. In the temporal condition, it relates to the

structuring of different temporal rhythms. A term also used to refer to different temporal scales is *'durée(Nowotny, 2016).'* Lastly, it also refers to the global versus local dichotomy.

In this chapter, I argue that scaling human infrastructure is unlike scaling a digital infrastructure where a simple numerical increase is scaling. I state that scaling a human infrastructure is much more than increasing the number of actors or entities in the infrastructure but instead entails a calculated situational, contextual increase by bringing onboard actors and entities with access to specific scalar operations to obtain scale. Other scholars within human geography characterize such scalar strategies as scale jumping or scale bending(Smith, 2004). I then demonstrate how the concept of scalar devices could be employed to understand how to scale human infrastructures. Focusing on the SS project, I show how the project teams use scalar devices to maintain collaboration, how scalar devices bring about emergence, and how scalar devices are part of knowledge production.

Contextually in the discourse around scale and scaling, one cannot do away with the notion of scale as that also means doing away with scaling. It is essential, especially in the framing of the Anthropocene age, as a scale issue for a reframing of how multiple views of scale could be beneficial in dealing with the moment. In the context of human infrastructure, there is a need to critically evaluate what human infrastructures have to do with climate change? To understand and contextualize human activities as primarily

causing climate change and other effects under the Anthropocenic age, we also need to understand the scales and scaling of human infrastructures.

I want to finalize by highlighting an anecdote to clarify further the situational elements that come to bear when scaling. I specifically want to highlight the higher scale effects in infrastructures and how scaling stopped, albeit briefly. Among the early institutions partnering in the SS project was OpenCity. OpenCity is a local chapter of a national program that embeds local civic technologists in local governments to work on civic problems. Though OpenCity was active in the project, it eventually disengaged with the project. This disengagement was not because the local institutions and members were not in alignment but rather because the national chapter did not see collaborating as beneficial. The OpenCity group did receive funding from the national program. Although they intended to deploy some of that grant to work on local issues in conjunction with the SS project, actors operating at higher-order scales led to the disengagement as they did not see the need for the collaboration. The local was in alignment, but the national scale was in tension with the local scale.

CHAPTER 7. CONCLUSION

This dissertation reconsiders the concepts of scale and scaling in the context of infrastructure studies. It also recasts the Anthropocene as an issue of scale and scaling at heart. This linking is intentional as I argue that for us to evaluate this 'age of man critically,' it is necessary to think through the role of infrastructures in the construction of this age. The common understanding of the industrial age as a demarcation for this age's genesis also points to the role that infrastructures play. For instance, other scholars have highlighted the role of the clock as an infrastructure. Others have highlighted how the history of the railway as infrastructure could be considered part of this age. Thus, recasting infrastructures and their contribution to this Anthropocenic age is relevant to understanding scale.

However, this dissertation explores the relationship between scale, scaling, and infrastructures. The primary position I make is the multi-scalarity of infrastructures. The discourse around scale within infrastructure studies had primarily centered on the local versus global dichotomy. The description of infrastructures as occurring when tensions between the local and global are resolved is the typical lens through which some analyze scale. Others build on this position claim that infrastructures occur when tensions between the short- and long-term are resolved. In this dissertation, I extend both positions to claim infrastructuring entails much more than resolving tensions between the local and the global or the short- and the long-term. I further argue that the notion of resolving tensions is scaling in practice. Tensions are manifestations of non-scalability. I make an

effort to explicitly make this position as it is not as explicit in infrastructure studies literature.

In this dissertation, I extend the notion of scale by introducing the concept of scalar assemblages. Scalar assemblages refer to the different scales aligned for an infrastructure to work. I also argue that infrastructures entail an active resolving of scalar tensions. By exploring these two dual positions, I highlight the necessity of scale as a concept and the multiplicity of scale. Within the scale debates, I build on scale as a relation and highlight the need to think of scale and scaling at the same time. Most scholars within human geography have primarily thought of scale as simply part of graduated levels socially constructed. Secondly, I highlight the multiplicities of scale, unlike in geography, where scale takes a universal perspective. This dissertation provides a mechanism through which one could discuss the different multiplicities of scale. Though scholars operating within environmental humanities specifically Horton points to this, this dissertation, specifically, presents scalar assemblages as a way to understand the multiplicities of scale.

Several scholars, such as Edwards, argue that infrastructures navigate across scales(Edwards *et al.*, 2007). Others have analyzed scale through different lenses. Ribes and Finholt make a case through their scales of infrastructure framework(Ribes and Finholt, 2007). Others have presented scale from a perspective that represents geographic reach(Ribes, 2014; Karasti and Blomberg, 2018). Edwards also provides a view of scale along the local versus global axis(Edwards *et al.*, 2007; Edwards, 2010).

This dissertation illustrates how infrastructuring is a process of scalar constructions across space and time. It extends this further to look at how scaling occurs across different scales. I provide evidence by exploring three sub-claims. I introduce the notion of spatial embedding to illustrate the utilization of embeddedness as a scaling mechanism. I explore the tactical moves the SS project takes to embed its infrastructure onto other structures to obtain scale. I make an active distinction between standardization and embedding to illustrate how embedding can be tactically employed to achieve scale. I analyze embedding along three threads. I explore embedding that comes about due to place. I demonstrate how scale and place affect where infrastructure sits. I then turn to embeddedness engendered by networks, highlighting how networks present a unique embedding. Finally, I explore embeddedness brought about by social structures.

The other sub-claim I explore is the reframing of resolving tensions between the short and the long-term as a temporal scaling form. I illustrate how the short term and the long-term and linked through infrastructural accretion, which is temporal scaling. I specifically draw on Oren Young's work, which makes the case that temporal scaling is the application of propositions from one scale to another. I extend this further to demonstrate that temporal scaling is the translation from one temporality to another and mediated by clock-time for scaling.

I lastly explore what does it mean to scale a human infrastructure. Unlike say computers, where scaling is a simple increase in computing resources, scaling human infrastructure entails a scalar contextualization. In this form, scaling entails the contextual

incorporation of a person or entity with access to specific scalar operations. It is about adding people and institutions that have access or their practices operate at a particular scale.

This dissertation foregrounds several things from my perspective. Firstly, it relooks at infrastructuring as part of the Anthropocenic age, especially from the perspective of scale. Both the Anthropocene and infrastructures deal with matters on scale. In the case of both, they present or refer to the state of becoming. Both are creatures or constructs of accretion. The Anthropocene entails how human activities have developed over a long temporal scale to the point that it is considered a geological epoch. Similarly, infrastructures are also long-term and entail developing over time. The juxtaposition of both infrastructures and the Anthropocene helps orient us towards thinking about how large-scale issues such as climate change. Also, we know about climate change because infrastructure useful in generating climate knowledge exists(Edwards, 2010). Similarly, to think through how to resolve such large-scale issues, we need to think them through from an infrastructuring lens.

Secondly, this work brings in different perspectives on scale. However, what I think stands out is the notion of scalar collapse as argued by environmental humanities. In the case of climate change, prescriptions on tackling something complex are reduced to the individual as other large-scale interventions are out of consideration. An example here could be the emphasis on personal responsibility in matters of carbon footprinting as opposed to something like a national environmental policy where interventions may

provide better outcomes. A manifestation of this scalar collapse is present in infrastructure studies' discourse, especially by positioning the local and the global as adversarial. The positioning has resulted in what geographers call the 'local trap' where interventions almost always occur at the local scale(Purcell and Brown, 2005; Russell, 2019). By exploring the multiplicities of scale and its construction, we also understand scaling. More important, looking at multiplicities of scale also enables us to comprehend and marshall different scalar strategies when confronting challenging and complex issues such as climate change.

Another perspective that I think this dissertation puts forth is contesting the conflation of the local. The positioning of the local has often been seen dualistically as oppositional to the global. Scales such as the homestead scale, the regional scale, or the national scale have been subsumed by the local. Evidence of this in the SS project is the use of 'hyperlocal' highlighting the deficiency of the 'local'. However, the relationality of the local seems to disappear when discussing infrastructures. The local, just like infrastructures and scale, is relational. Considering elements such as scaling in relational terms helps us understand different constructed scales in an infrastructure. Moreover, considering both scale and the local in tandem helps us critically think about scaling at the local.

More importantly, though, is this dissertation also presents a mechanism to think through scale imaginaries as consisting and influenced by other scales. For instance, in the homestead case, as a scale understood within the context of scale assemblages,

several scales converge at the homestead level. The story of Levittown as suburban sprawl highlights how the design of the homestead was affected and set up for the provision of public services. Another element of this scalar assemblage is that the homestead is the site for reproduction. The matter of reproduction is a position highlighted by Marston(Marston, Jones and Woodward, 2005). Although disciplines such as geography may limit scale to a specific extent or scope, I argue that considering the positionality and interdependency of scalar categories to other scales is essential. Considering *scale* and *scaling* in tandem is useful. Thinking of the notion of a smart city, other than thinking of the city as a scale, thinking of how other scales are embedded and aligned to the city scale is essential.

Beyond the matters of scale and scaling to researchers and practitioners of infrastructure studies, several aspects of this dissertation are broadly applicable to other fields. Understanding the social construction of scale is instructive as it allows us to also think about how scales and scaling are defined. More importantly, thinking through scale enables us to move beyond a state of debilitating paralysis when confronted by tough, complex issues that seem insurmountable. The field of environmental governance provides an excellent example of how scales are constructed and governed. I hope this dissertation will help scholars think beyond the local versus global dichotomy, allowing us to explore those scales often at the periphery.

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