Considerations of Co-Creation in Devising an Autonomous Cyber Physical System for Real Time Flood Intelligence in an Operational Framework - Development and Adoption

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

Flooding is a prevalent natural catastrophe that poses a significant threat to people's livelihoods and results in substantial economic losses in damages each year. Coastal engineering efforts involving flood forecasting have been implemented to mitigate these impacts, but there are global disparities in the adoption and perception of such smart city systems for pluvial flood predictions. Wiebe E. Bijker analyzes the difference between American and Dutch coastal engineering, which can be used to understand these disparities. As compared to the United States, a country like the Netherlands, which is historically known for being low-lying relative to sea-level, hasn't had any recent disasters to the scale that the United States has. After the occurrence of Hurricane Katrina in New Orleans, an analysis of appropriate preparation, response, and expectations comes into question. This occurrence can be extended to stark differences in smart city technology adoption throughout the world as there are two polarized attitudes towards smart city adoption. One of the major sentiments is hopefulness and as Michael Bloomberg puts it, "Smart cities can help us create a more sustainable, equitable, and prosperous future for all" (Bloomberg Philanthropies, 2023). Cathy O'Neil, on the other hand, voices her fears as she says, "Smart cities could exacerbate inequality by further concentrating wealth and power in the hands of a few" (O'Niel, 2018).

The current state of advancements in coastal engineering in terms of physical infrastructure might be sufficient but devastating catastrophes still occur throughout the world, which can be attributed to the lack of appropriate preparedness and preventive response. With this, it is important to note that there are knowledge gaps in relation to predictive technologies that prevent insights from being utilized to better prepare. Pluvial flooding, for example, is caused by heavy rainfall, and it can occur even in areas that are not traditionally considered to be flood-prone (Rozer, 2021). Smart city technologies for pluvial flooding prediction are still in their early stages of development, but offer accurate predictions (Ke, 2010). Furthermore, there is a lot of research being done in this area, and it is likely that smart city technologies for pluvial flood forecasting will improve in the near future, but the issue of adoption still remains. There seems to be clear benefits for municipalities and businesses proposing smart cities but how and when citizens reap benefits is rather vague in several scenarios. Without using predictive technology, foresight and intuition about appropriate infrastructure allocation will be missing and economic loss through damage will remain a problem. For context as to the scale of potential damage, in 2020, floods were estimated to result in six thousand deaths globally and resulted in costs over two hundred billion United States dollars (NWS, 2020). But even with the use of smart city technologies, citizen resentment and distrust is prevalent.

Immediately, we can argue that the different regional adoption of smart city systems for pluvial flood forecasting, traffic management, sanitation, etc. can be attributed to a combination of factors, including risk assessment and perception, economic development, and cultural factors. Bijker analyzed the semantics and framings in papers to convey the stark differences in risk assessment and perception of the United States and the Netherlands. Through a similar analysis of the semantics, framing, perceptions, and the interaction of relevant actors, this work provides an alternative interpretation of the reasoning behind adoption disparities and approaches to addressing the issue.

Problem Definition

Major Players and Hurdles in Smart City Adoption

In the adoption of smart city forecasting systems, there are two major actors from a macroscopic perspective: municipalities and residents. Municipalities are primarily concerned with identifying the need for smart city systems within communities, developing policies/regulations that support or oppose the deployment, and securing or allocating resources and funding. The Wireless Infrastructure Association states that the above mentioned tasks are not so straightforward as “each municipality, government and/or entity must understand its own financing structures, limits and opportunities as a starting point” (WIA, 2018). The other key player in the adoption of smart city technology is residents, who share feedback to municipalities, advocate or critique smart city initiatives, and potentially utilize smart city forecasting systems. A common theme that comes up in discourse related to project adoption is the concept of “high-tech governance and citizen participation”, which shows that there is indeed interplay between municipal control of smart city initiatives and sentiments of citizens (Esashika et al., 2021). With this, it seems that the level of cooperation between citizens and the governing organization ultimately dictate how successful adoption efforts of smart city solutions are. Working towards the above claim of cooperation, we can look to the example of contrast between Copenhagen, Denmark and Toronto, Canada with respect to smart city adoption. With the promise of “higher quality of life” for citizens, Copenhagen has one of the most successful rollouts due to the trust and cooperation of its residents and is able to offer intelligent traffic system frameworks, flash flood prediction, and energy saving infrastructure (Quelin & Smadja, 2021). Alternatively, in Toronto, Canada, Alphabet’s Sidewalk smart city initiative was shutdown due to resident outcry as “the project’s tech-first approach antagonized many; its seeming lack of seriousness about the privacy concerns of Torontonians was likely the main cause of its demise" (Jacobs, 2022).

Before proceeding, it would be valuable to formally define the general mechanisms by which smart city systems work. In the context of pluvial flooding, a smart city forecasting system utilizes a combination of sensors, data analytics, and modeling to predict the risk of pluvial flooding. Sensors are used to collect relevant data such as rainfall, river stage, temperature, and other factors that can contribute to flooding. This data is then analyzed using sophisticated algorithms to identify patterns based on previous supervised training or heuristics.

As seen in Figure 1 below, there are several different types of sensors and modalities of data that can be used in training and running inferences on them in real time. The overhead of streaming and synchronizing all the different types of data does often become a limiting factor as "the lack of uniformity in data standards between agencies can become problematic, and the integration is too complex from a technical perspective" (Sims, 2021). Knowing that, we can proceed to mention a third stakeholder that is business/researchers that are responsible for the development of smart city technologies. In addition to developing smart city systems, many private organizations commonly align their corporate narratives with smart city solutions and because of that they have "overinflated public expectations of smart cities while not offering sufficient reflection by society about some of the social concerns introduced by new smart city solutions" (Law & Lynch, 2019). Again, we can turn to the example of Alphabet's Sidewalk Labs project, in which an affordable and inclusive city was promised to residents, but concerns about gentrification and displacement were brought up and unmet (Jacobs, 2022). There is a stark contrast in citizen sentiment of smart cities between Copenhagen and Toronto, which largely dictates their course for adoption as citizens are a major actor.

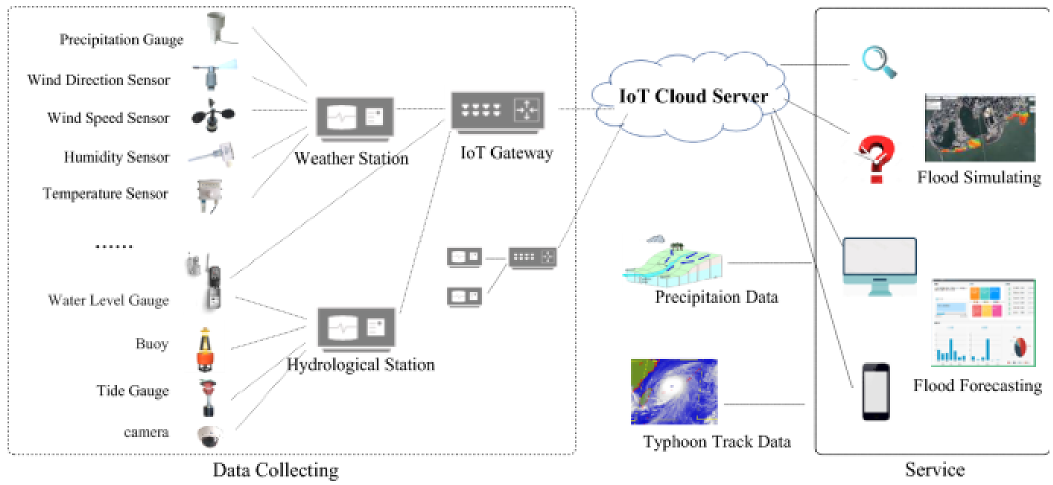

Figure 1 - Example Workflow of Pluvial Flood Forecasting Cyber Physical System (Dai et al., 2021)

Parallels in other Coastal Engineering Practices, Analysis of Bijker's Coastal Engineering Comparison

In "Differences in Risk Conception and Differences in Technological Culture", Bijker's central claim is that the difference in coastal engineering styles can be rooted back to different societal conceptions of risk. There are stark historical differences in societies that create different awareness and perception of floods. Bijker, through analysis of "Dealing with Distributed Responsibilities for Flood Hazard" shows that Americans have "little interest in funding studies and works" (Wiegel & Saville, 1996: 519), where as the Dutch had rulings dating back to the thirteenth century in which "everybody had to pay for the maintenance of the dikes: 'the monastery, the knight, the priest, the common man, everybody alike'" (Bijker, 2006). In modern society, the Netherlands and other Northern European and Scandinavian countries are well known for having a technological culture, which is bound to be a heavy influence in their adoption of smart city projects. With this, varying technological cultures and levels of risk aversion are a contributing factor to the discrepancies in adoption of such systems.

Another striking difference that is shown between American and Dutch coastal engineering styles is that the United States has adopted a reactionary protocol while the Netherlands has preventative solutions. To this point,"the American (engineering) practice focuses on predicting disasters and mediating the effects once they have happened, in brief: on 'flood hazard mitigation'. Dutch practice is primarily aimed at keeping the water out" (Bijker, 2006). Given these current approaches to coastal engineering, smart city developments seem more useful for a country like the Netherlands.

One question that can be brought up in regards to the above mentioned displays is why there exists a contrast in response and attitude towards coastal engineering solutions between developed nations and what does this contrast originate from? To this, a potential explanation is that the US political culture can be characterized as "neo-liberal, without belief in the common good as something that the government should define and protect; there is an inclination to privatize and individualize public functions, rather than to defend their value" (Mukerji, 2006). This ideology doesn't necessarily persist in the Netherlands, but might slowly be "emerging in the Netherlands too, the political culture is quite different, with a much more accepted central role for the national state in all sectors of society" (Bijker, 2006). In this above comparison, it becomes apparent that the United States has a culture that promotes little technological and more privatization than the Dutch, and these varying perspectives on the role of municipalities in these nations does set the trajectory for smart city adoption.

Methods

Analyzing Semantics and Framing of Contrasting Primary Documents

Bijker's work uses historical perspectives from America and the Netherlands to contrast the differences in their coastal engineering. He uses discourse analysis to compare the different ways that risk is conceptualized and managed in the United States and Netherlands. There are indeed different discourses in relation to risk and management in these two countries and because of that we are able to see the stark differences in disaster outcome and response.

An analysis of the framing and semantics in relevant discourses exposes the varying societal perceptions toward smart city integration. There are different discourses that need to be analyzed in order to delve into the regional cultures revolving around adopting new technologies. Municipal, financial, and technological documents ultimately showcase the varying prominence of relevant concerns in relation to technological advancement for flood prediction and preparedness in different regions of the world (Neupane et. al. 2021). As seen in Figure 2 below, there are several hypotheses for several technological, organizational, environmental, and security variables. There are several hypotheses about the displayed factors positively or negatively affecting trust in smart city technologies, which ultimately influences the stakeholder's intentions of adoption. When referring to relevant primary documents from the perspective of various stakeholders, such hypotheses can be used to gauge likeliness of adoption.

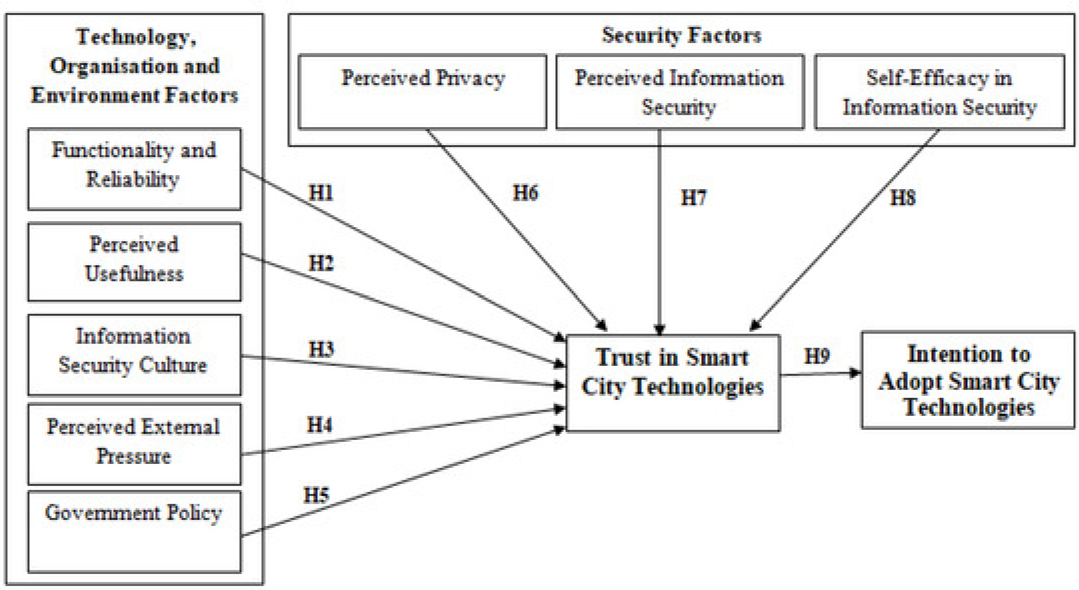

Figure 2: Smart City Technology Adoption as a Function (Neupane et. al. 2021)

Expanding upon the importance of discourse analysis in the context of smart city system adoption and development, it becomes evident that examining the perspectives of various populations can certainly enhance the tailoring of such solutions to specific nuances on regional and cultural levels. Understanding the diverse discourses surrounding the adoption of new technologies is crucial for identifying potential barriers and enablers and also crafting solutions that work with the concerns and priorities of different regions. By delving deeper into the viewpoints of various stakeholders, such as municipalities, financial institutions, and technology experts, we gain valuable insights into the differing priorities and expectations that each delivers.

Actor Network Theory in Cyber Physical System Development and Adoption

Actor-Network Theory is another valuable framework for analyzing the adoption of cyber physical systems as it provides a way to examine the interplay of stakeholders and their dynamic relationships in shaping the development and adoption of these technologies. It is important to note, however, that above the major stakeholders that were identified as actors was rather comprehensive and the actors that are being identified for particular situations could very well be more granular. Furthermore, there could even be non-human actors that have significance in such interplays that weren't necessarily explicitly defined above or mentioned. With respect to a scenario involving flood intelligence smart city technology adoption, some rather granular, non-human actors include the particular sensors being used, Internet-of-Things devices, communication infrastructure, and potentially intelligent algorithms/models, all of which make up a cyber physical system. Legislation is a separate, non-human actor that has multiple sub-actors such as aspects of the legislation that work to promote or hinder adoption and even development of smart city technology. Figure 3 below shows an example of what the major actors and the network between them might look like in the context of adopting a smart city system for elderly care.

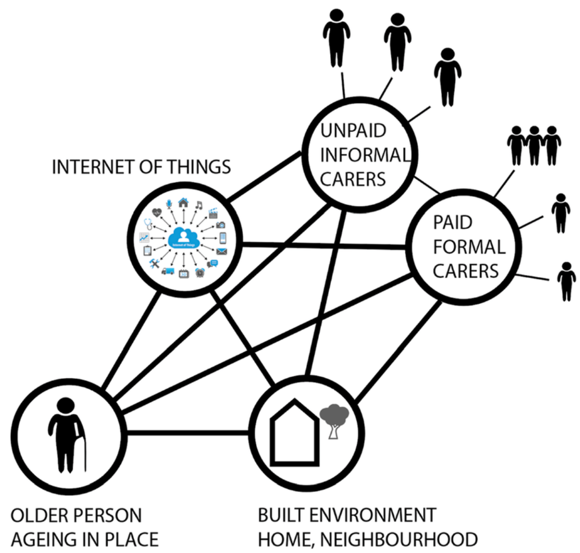

Figure 3: Example Actor-Network Theory Illustration of Smart City Interplay in Elderly Care (Carnemolla, 2018)

The concepts offered by Actor-Network Theory have the capability to serve as a guiding framework for promoting the adoption of such smart city technologies. By comprehending the various actors and their various networks, such a tool assists in crafting tailored strategies to facilitate the integration of Internet-of-Things into diverse geo-political/social contexts. From the perspective of smart city developers/providers and policy makers, having awareness of the network of human and non-human actors could very well provide some insight on how to customize strategies to suit the unique needs of a given geographic region. The recognition of cultural and environmental factors is crucial for the successful integration of technology in diverse urban and rural settings, ultimately, ensuring that smart city solutions are well-suited to locale.

Results

This research has significance in breaking down the underlying intricacies of differences in perception of smart cities as well as their adoption and development. There is likely to be no direct impact on municipality/citizen adoption or private company development of pluvial flood prediction cyber physical infrastructure as the reach of this research is limited. However, this research provides a robust analysis and comprehension of regional discourses throughout the world that could certainly be useful for global standards related to smart city projects for protection against natural disasters. This research also suggests adjusting strategies to encourage adoption of smart city technology or to change practices in development to foster trust through more distributed involvement of stakeholders, which in turn is a catalyst for shifting perceptions revolving around coastal engineering for pluvial flooding.

The balance of stakeholder involvement seems to be the foundational element that underpins the successful implementation of smart city initiatives. The relationships between municipalities, citizens, and private business in this context requires a balance of effort in developing trust on all fronts. From the perspective of municipalities, instilling trust among citizens by involving them in the development process and decision making, demonstrating transparency in intentions behind smart city projects, offering open communication/critiques, and ensuring data privacy are appropriate steps. Private companies often play a pivotal role in providing the solutions and expertise required for implementations of the cyber-physical system infrastructure so trust established through contracts, performance metrics, and collaboration agreements would ensure benefit to both parties. Conversely, it is important for private businesses to establish trust with municipalities and citizens. Figures 4 and 5 show the contrast of stakeholder interaction between the municipalities, private businesses, and citizens in Toronto and Copenhagen smart city developments respectively. In Toronto, there is a disconnect of correspondence from private businesses and municipalities to citizens as compared to Copenhagen where clear communication between purposes and expectations are conveyed to citizens. In the case of the Toronto smart city effort, the provision of relevant data by citizens wasn't necessarily voluntary and on top of that the self-efficacy of information security wasn't well established. A citizen science framework could instead be used where citizens are encouraged to participate in data collection and contribute to decisions, which will instill self-efficacy and in turn establish trust. By showing commitment to ethics, security, and support, stakeholders are more likely to get involved.

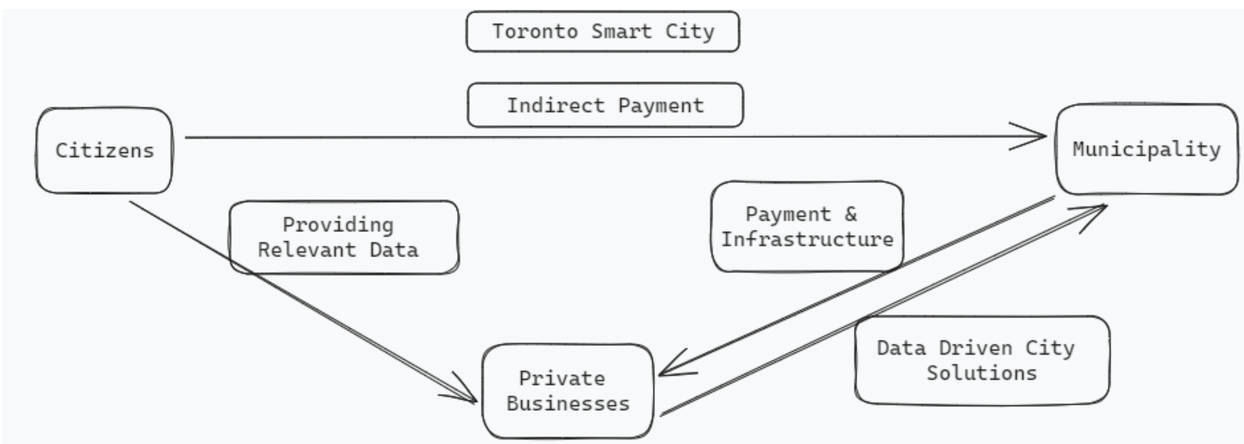

Figure 4: Interaction Between Stakeholders for Toronto Smart City

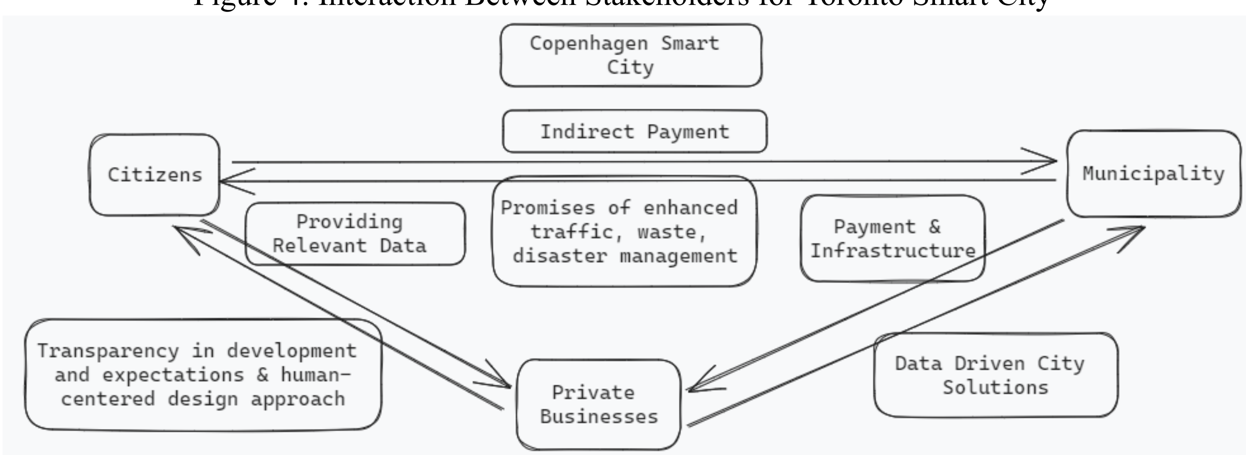

Figure 5: Interaction Between Stakeholders for Copenhagen Smart City

More citizen involvement is necessary through the various stages of smart city development and adoption. This research highlights regional disparities in perceptions about smart city technologies and suggests the broader need for citizen involvement, in particular, from the stages of development to post-production usage. Crowdsourcing is another example of a general process that incorporates citizen effort and correspondence with the other stakeholders, through proper incentives, which in turn, works to develop trust and change past perceptions. More equal stakeholder involvement, as the foundation of smart city initiatives, can ultimately lead to a more resilient and responsive urban environment that is better equipped against the potential impacts of natural disasters.

Conclusion

This analysis works towards the claim that successful adoption and utilization of smart city systems require cooperation between private businesses, municipalities, and citizens. It also highlights that societal perception of coastal engineering efforts and policy serves as a barrier that explains the regional discrepancy in system installation.The exploration of regional risk perceptions, trust dynamics, and interaction between municipalities, citizens, and private businesses within the context of general smart city development reveals the various intricacies that go into successful implementation. Furthermore, the results of this research provide an approach to garnering more trust and changing perception with more citizen involvement through the stages of the smart city development and adoption. Crowdsourcing and citizen science, which were previously mentioned, are suitable frameworks for incorporating citizens into the development process and could be further encouraged through government tax-breaks, as an incentive. Garnering such involvement develops the citizens' self-efficacy revolving around data and information, which works towards trust and positive perceptions of smart city efforts.

It is important to note that there are indeed limitations of this research. In the use of Actor-Network Theory, only the most immediate and macroscopic stakeholders were analyzed due to scenario specifics being a limiting factor. Similarly, with the analysis of framing and semantics, a more thorough review of the relevant literature and primary documents is necessary. With regards to the new insight about the need for more distributed involvement in smart city efforts, there should be a more formal analysis of existing approaches. Nonetheless, the insights into the critical role of stakeholder involvement can be used to provide direction for future research into development and adoption of cyber physical systems. This research also underscores the significance of tailoring smart city initiatives to the unique needs and concerns of different communities, recognizing that a standardized approach may not be effective. In acknowledgement of the limitations of this research, it sets a precedent for future investigations into the development and adoption of smart city systems and the need to incorporate the regulation of the interaction between major stakeholders throughout the various stages.

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