Smart Cities designed by Smart Communities: An Engaged Approach to Develop a Sociotechnical Network.

Oswald Jenewein[1], Michelle A. Hummel[2], Karabi Bezbourah[3], Yonghe Liu[4], Kathryn Masten[5]

[1] School of Architecture, University of Texas at Arlington, 601 W. Nedderman Drive, Arlington, TX 76019; email: oswald.jenewein@uta.edu

[2] Department of Civil Engineering, University of Texas at Arlington, 416 Yates Street, 430 Nedderman Hall, Arlington, TX 76010; email: michelle.hummel@uta.edu

[3] Department of Public Affairs, University of Texas at Arlington, 601 W. Nedderman Drive, Arlington, TX 76019; email: bezborua@uta.edu

[4] Department of Computer Science and Engineering, University of Texas at Arlington, 416 Yates Street, 430 Nedderman Hall, Arlington, TX 76010; email: yonghe@cse.uta.edu

[5] Maritimatix, P.O. Box 1, Vienna, MD 21869; email: kathryn@maritimatix.com

ABSTRACT

In the process of developing a smart city framework, sensor data are crucial to enable cities and communities to make informed decisions on future plans. Involving community-based organizations and residents is an integral component of this process to ensure equity and accessibility of data. This study aims to develop a sociotechnical network to (1) identify vulnerability zones, (2) measure data on flooding, air, and water quality, and (3) inform community members and decision-makers through a data dashboard. A small coastal town in the Texas Coastal Bend Region is utilized as a case study.
Methodologically, this study utilizes Participatory Action Research to frame a mixed-methods approach toward developing a data dashboard. This research project is a practical guide for engaged scholars in the social sciences, engineering, and urban design fields. The outcomes include recommendations for the engaged community and provide a data-dashbord targeting academic and non-academic audiences, residents and decision-makers.

Keywords: Climate Resilience, Coastal Adaptation, Vulnerable Communities, Participatory Research

INTRODUCTION

As climate change imposes new challenges on urban landscapes, cities need to develop adaptive strategies to combat these changing environmental conditions (Hunt and Watkiss, 2011). Besides the naturogenic impacts arising from climate change, industrial development and other anthropogenic activities also pose a threat to cities and communities. However, in many cities, a lack of data needs to be bridged to enable decision-makers and community members to make informed decisions on future plans. Such data are essential in evaluating strategies for adapting the built environment. In recent years, smart city concepts have been developed around the globe. The integration of sensors to gather quantitative data to inform decisions is widely accepted (Su, Li and Fu, 2011; Anthopoulos, 2015). Smart city concepts can integrate technology-based approaches into sociotechnical networks. Activating local knowledge by engaging the actors who live within and shape the urban environment is a crucial component of designing smart cities (Cardullo and Kitchin, 2019). Kopackova and Libalova, 2017 describe the integrated nature of social and technical systems as a premise for a smart city concept. Breuer, Walravens and Ballon, 2014 identify "smart citizens" as the most important component of developing a bottom-up smart city concept. Building such a participatory sociotechnical network with stakeholder engagement allows different actors to become part of the development and application of the respective strategies (Dameri, 2013). While the literature already emphasizes the importance of stakeholder engagement when developing a smart city concept, this paper applies a participatory mixed-methods approach to developing socio-technical networks to the City of Ingleside on the Bay (IOB), Texas: a small Texas coastal town that experiences naturogenic and anthropogenic environmental impacts yet lacks sensor-based information on flooding, air and water quality. The aims include (1) identifying vulnerability zones, (2) measuring data on flooding, air, and water quality, and (3) informing community members and decision-makers through a data dashboard.

Utilizing Participatory Action Research (PAR), this paper brings together a bottom-up approach, building a sociotechnical network that identifies hazards and informs residents of potential threats as an initial step to developing a smart city concept for IOB. This approach acknowledges local knowledge as a smart source of information that informs the technical components of the network and therefore integrates human and artificial spheres.

MATERIALS & METHODS

Study Area

IOB is a small coastal city located at the northern shoreline of Corpus Christi Bay, at the intersection of the La Quinta and Corpus Christi Ship Channel (Figure 1). IOB has 762 residents, 73% white and 26% Hispanic, average age 51, per capita income $39,159, 3.5 % below the poverty line, and median home value of $220,300 (US Census, 2020).

IOB is on the front lines of a rapid industrial development that began when the Naval Station Ingleside (NSI) closed in 2010, after operating on 1000 acres of land adjacent to IOB on the Live Oak Peninsula. A ceremony in 2010 marked the formal takeover of the property by Port Corpus Christi. In 2012, Oxy Chem (part of Occidental Petroleum Company) bought the former base property, including over 400 acres of wetlands. In 2015 the longstanding ban against U.S oil exports was lifted (POCC, 2018). In 2018, Occidental sold the property to Moda Midstream, a crude oil export terminal for very large crude carriers (VLCCs) (Blackmon, 2021). In 2019, Cheniere began liquefied natural gas (LNG) export operations, with LNG tankers for its first three "trains" traversing La Quinta Ship Channel as close as 150 feet from IOB on their way to and from Cheniere's site near Portland (Chapa, 2019). In 2020, South Texas Gateway Partners (STGP) began oil export operations on the Peninsula (BuckeyePartners, 2020). By 2020, Moda, STGP, and Flint Hills Resources, a third oil export terminal located on the Peninsula, accounted for half of the exports that propelled Corpus Christi to become one of the US' leading crude export hubs (POCC, 2021b). In 2021, Enbridge bought the Moda property for $3 billion. In 2022, Enbridge announced plans to construct a $3 billion blue hydrogen facility on the former base property (Ramirez, 2021).

To address the rapid industrial growth, a community-based organization formed in 2019, the Ingleside on the Bay Coastal Watch Association (IOBCWA), bringing concerned neighbors together to address environmental issues, such as increased erosion, flooding, and relative sea level rise, destruction of seagrass, wetlands, live oaks, and wildlife habitat, and worsening air and water quality. IOBCWA now partners with other community-based organizations, like the Indigenous Peoples of the Coastal Bend and the Karankawa Kadla, to fight environmental impacts (IOBCWA, 2022).

With increased industrial activity, new plans might impose additional stress on the community and its coastal environments. For example, the deepening and widening of the ship channels adjacent to IOB and the construction of desalination plants nearby may impact water and air quality (POCC, 2021a).

Figure 1. Map of IOB, showing the proximity to industrial zones and ship channels.

Participatory Action Research (PAR)

The PAR approach served as an umbrella for several mixed methods applied in this study. PAR has three primary objectives: (1) enabling action on the research topic, (2) sharing power between researchers and community partners, and (3) involving participants as active players in the study (Reason and Bradbury, 2001). It is a type of applied research that builds the initial research question with a community and intends to develop concrete outcomes useful for the engaged constituents and decision-makers (Ozanne and Saatcioglu, 2008).

This study builds on a previous participatory research project conducted by Jenewein and Hummel, 2021, following up on residents' request for environmental monitoring. Therefore, the research team had already established relationships and formal agreements for collaboration with community-based organizations (CBOs) in IOB. These relationships with local organizations are crucial to bringing together a broad alliance of residents, civic and governmental leaders.

Community Workshops

Over the term of 12 months, the PAR framework aimed to (1) hold a community workshop to co-create the initial steps towards developing a smart city Framework with residents, (2) identify locations for sensor placement, (3) develop a data dashboard to report on flooding, air and water quality, and (4) conclude with a beta-testing workshop to gather community feedback on the dashboard.

The first community workshop covered a broad range of topics, identifying (1) assets, (2) challenges, and (3) strategies to develop concrete (4) actions on the respective topics of flooding, air and water quality (Table 1). This assets-challenges-strategies-actions (ACSA) approach aimed to align community feedback with the sensor data collected later on. With approximately 30 participants, the workshop split the group into three focus groups on the respective topics. After 20 minutes, each participant switched the discussion table, so all topics could be discussed within one hour.

Table 1. Semi-Structured questionnaire for focus group discussions in the community workshop.

Assets	**What are the assets?** • What are some of your community assets? • Why do you consider them to be assets? • Is there something about where they're located that makes them an asset?
Challenges	**What are the challenges?** • Thinking about [air quality, water quality, flooding], what are the major challenges related to health, safety, and quality of life in IOB? • How concerned are you about the [air quality, water quality, flooding issues] in and around IOB? • What do you think are the main sources/causes of [air pollution, water pollution, flooding] in IOB? • What parts of the community and which members of the community are likely to experience the greatest impacts due to these challenges?
Strategies	**What are the strategies to overcome these challenges?** • What ideas do you have to address [air pollution, water pollution, flooding] in IOB? • How might efforts to address [air quality, water quality, flooding issues] impact jobs, property values, or economic prosperity? • How well are local, state, and/or federal government officials and agencies (like TCEQ and Port of Corpus Christi) keeping the [air, water, land] healthy, safe, and conducive for a high quality of life? • Which specific [contaminants, flood impacts] do you think are most important to measure and monitor, if any?

Besides the collection of community input on the mentioned topics, this workshop outlined the overall study and asked participants to self-identify as volunteers to allow sensor deployment on their properties. This approach highlights the integral role of the CBOs and actors within the community when developing a sociotechnical network.

Sensor Deployment and Data Collection

In-house sensor nodes were developed with the goal of obtaining an optimal tradeoff of low cost, reliability, and accuracy. Specifically, the air quality node measures CO2, PM2.5, SO2, NO2, along with humidity and temperature. The water quality node measures salinity, pH, and dissolved oxygen, along with water temperature and water level. We are able to reduce the cost of each type of nodes by about 60%, compared with existing off-the-shelf commercial products, while achieving comparable accuracy.

The sensor nodes are deployed at locations provided by the community members. Each node is equipped with a Long Range Wide Area Network (LoRaWAN) communication module, connecting to a central gateway with an Internet connection. Measured sensory data can then be directly backhauled to the server located on the UTA campus. This provides near real-time monitoring of the targeted community. Currently, only one gateway is deployed. Given that the coverage of LoRaWAN is a few miles, depending on the environment, covering the entire IoB community may require several gateways.

Community Dashboard Development

Currently, environmental conditions in the Coastal Bend are monitored with a low spatial resolution by several local, state, and federal agencies and private companies, but the resulting data either is not made publicly available or is spread across a variety of websites with different protocols for reporting and access. As a result, the data is not easily used by community members who want to know about conditions in their own neighborhoods. The PAR approach identified a need among community members to have access to real-time data on local environmental conditions in an easily accessible format.

Based on this community-identified need, the project team developed a preliminary web-based data dashboard to display real-time sensor data. The initial dashboard design was informed by input from the community workshop and included a landing page with a map of the community and markers for each available sensor. Users can select a sensor to be taken to another page with graphs for each parameter being measured. Information about each parameter, its sources, and its potential health effects are also included.

A group of 28 residents of IOB was enrolled as beta-testers and given access to the dashboard to test its usability and provide feedback. After approximately four weeks of testing, we gathered feedback via two platforms: an online survey and a virtual workshop. The survey asked users to rate the following aspects of the dashboard on a 5-point scale: navigation, overall design, design of data displays, the relevance of information displayed, and ability to understand the data presented. This was followed by an open-ended prompt to provide comments or feedback on the dashboard. The virtual workshop included a tutorial on the dashboard functionality, an exercise that asked participants to find air quality data at a certain time and location, and a discussion period to reflect on the exercise and other experiences with the dashboard. Beta-testers who participated in the workshop were given a $25 gift card as compensation.

RESULTS AND DISCUSSION

Community Workshop Outcomes

The initial community workshop held at the beginning of this study served as a framework for the community dialogue between the research team and the participants. It enabled a broad discussion on flooding, air and water quality, and helped to identify sensor locations based on community knowledge and experience. Content analysis of the data collected in the workshop assisted with identifying how frequently some of the items were mentioned, which indicated the importance of that item for the community. Table 2 categorizes and ranks the items from most to least mentioned in the community workshop.

Table 2. Ranked categorization of the data from the Community Workshop.

	Air Quality	Water Quality	Flooding
Assets	1. Southeast Wind / Breese 2. Bird Watching 3. Sailing 4. Increased Bird Population 5. Cooler Temperatures 6. Air Quality Sensors	1. Water Recreation 2. Wildlife 3. Water Quality 4. Ingleside Cove 5. Wildlife Sanctuary 6. Bahia Marina 7. Berry Island 8. Spoil Island 9. Flats Area	1. Water Recreation 2. Drainage Study 3. Bay is almost at Sea-level 4. McBluff 5. Communities Uphill 6. Efficient Water Drainage 7. Permeable Shoreline
Challenges	1. Affect on Respiratory Health 2. Industry Increasing Emissions 3. Increased Ship Traffic 4. Responsible Parties Deflect 5. Regulations aren't enforced 6. Bad Odors 7. Sulfide Fuel 8. Fertilizers and Pesticides 9. Decline in Biodiversity 10. Cancer-Causing Pollution 11. Dredging	1. Desalination Plant 2. Quality of Drinking Water 3. Ship Ballast Water 4. Aging Potable Water Infrastructure 5. Smell from Well Water 6. Drainage System 7. Drainage Check Valves 8. Standing Water 9. Erosion 10. Sea-Level Rise 11. Large Ship Traffic 12. Silting in Canals 13. Livelihoods / Property Values 14. Government-Industry Collusion 15. Lack of Community Involvement 16. Surrounding Counties Needs 17. Major Storm Events 18. Invasive Species Brought by Ships 19. Permanently Located Boats 20. Lack of Proper Testing / Regulation	1. King Tides 2. Ship Traffic 3. Dredging 4. Sea Grass Damage 5. Noise Pollution 6. Road Flooding 7. Standing Water 8. Major Storm Events 9. Limits Accessibility 10. Infrastructure Damage

Strategies	1. Lower Overall Emissions 2. Recognize PM 2.5 as a Pollutant 3. Utilize Air Quality Sensors 4. Emergency Alert System 5. App for Air Quality Alerts 6. Plant more Trees 7. Investment in Clean Energy 8. Local Checks and Balances	1. Drainage Study 2. Recycling Water 3. Replace / Maintain Pipes 4. Reduce Ship Traffic 5. Create a No-Wake Zone 6. Place Desalination Plant off Coast 7. Increase Resources for Conservation 8. Create a Baseline for Water Quality 9. Proactive Approach to Water Quality 10. Industry Water Pollutant Alert System 11. Create More Community Awareness 12. Limit MODA Pier from Expanding 13. Removal of Beached Boats	1. Drainage Study 2. Possible Levy 3. Reinforce Existing Properties 4. Better Drainage Systems 5. Elevating the Beach Club 6. Increase Infrastructure Funds 7. Reduce Shipping Traffic 8. Raise Bulkheads 9. Flood Insurance 10. Measure Tidal Surges 11. App for Flood Alerts 12. Proper Education about Floods

The outcomes of the community workshop, including the closing discussion, show that water is generally perceived as an asset to the coastal ecosystem and for recreational purposes. However, the risks associated with flooding and water quality concerned many workshop participants. The findings of a previously conducted drainage study have already increased the awareness of flood-related problems in the city. Residents also reported a perceived correlation between wind directions and industrial air pollution. A frequently mentioned comment included odors residents detected whenever the wind direction came from the industry located east of IOB. Additionally, residents were concerned about the impacts of air pollution and respiratory health issues. Increasing industrial development, canal dredging, and ship traffic are concerns affecting all three categories of water and air quality, and flooding. Deploying sensors to identify various air pollutants, improving drainage and stormwater infrastructure, and elevating structures were mentioned as potential strategies.

Sensor Deployment and Data Collection Outcomes

The sensor network was deployed successfully, having provided continuous monitoring of the targeted community. Maintenance of the sensors has been an ongoing challenge, though, as the harsh coastal environment, particularly seawater, has introduced biofouling to various surfaces. As a result, we have now targeted a cleaning frequency of the sensor nodes at least once per month.

We developed a data dashboard that displays the sensor measurements on a map of the area for real-time visualization. Other relevant data from existing research-grade monitoring stations, including nearby air and water monitoring stations, and a recently installed air quality monitor by the community, are also displayed.

The dashboard is currently available for web-browsers only. Mobile apps and other platforms will be added to allow stakeholders and the public to monitor environmental conditions throughout the community.

The team gathered several months of monitoring data that are currently being vetted, analyzed and calibrated to ultimately provide community members with a comprehensive overview of environmental monitoring data.

Community Dashboard Development Outcomes

Overall, the beta-testing process led to the identification of several key improvements that will be incorporated into updated versions of the dashboard. A main concern expressed by beta-testers was the difficulty in viewing some of the dashboard features on a smartphone. Given that many users are likely to use their phones when accessing the sensor data, it is critical that the dashboard can be viewed seamlessly across multiple platforms (i.e., computer, tablet, phone). This will be a priority of future development efforts. In addition, beta-testers also expressed that it is difficult for a non-technical user to know when the reported parameter values are normal versus when they should be considered “high” or “unhealthy.” Participants suggested showing acceptable values and regulatory limits on the data displays to help contextualize the sensor values so users can more easily identify when they need to take action or engage in mitigating behaviors.

One challenge of the dashboard evaluation and beta-testing effort was the low participation rate by those who enrolled in the program. Of the 28 people who enrolled as beta-testers, five people provided online survey responses, and seven attended the virtual workshop. While those who participated still provided valuable feedback and insights into the usability of the platform, future work will focus on developing strategies to engage a broader cross-section of community members in evaluation efforts.

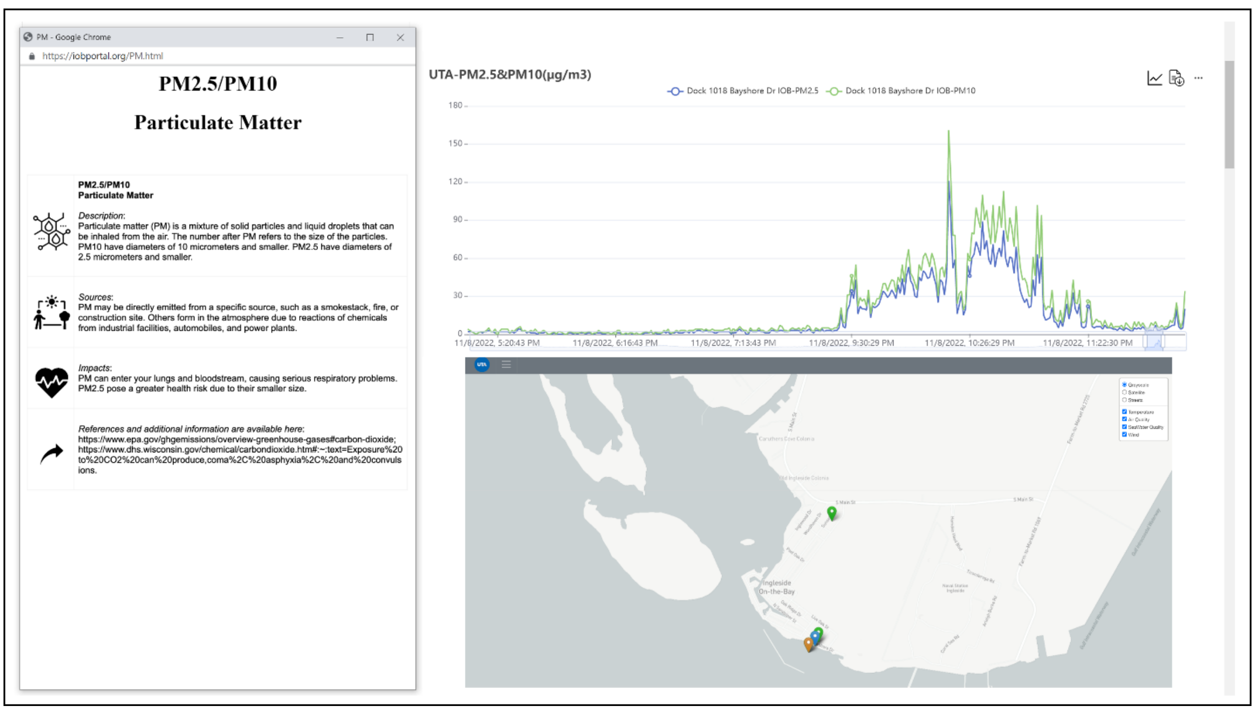

Figure 2. Data Dashboard showing PM2.5 & PM10, and an overview of sensor locations.

CONCLUSION AND RECOMMENDATIONS

While the developed data dashboard does not create a smart city, it is a first step to delivering a data-driven assessment of environmental impacts. The bottom-up approach in this participatory study has proven to be a great tool for building a research framework with stakeholder involvement. Identifying sensor locations and deploying measuring stations on private properties as residents volunteered to participate in this study was a crucial component to successfully establishing the sensor network. The gathered data will help to inform decision-makers and community-based organizations on future decisions, from comprehensive development plans to community development. The data could also inform county and state-level decisions on future deployment locations for EPA-grade sensors.

The next steps include calibrating the sensors with EPA-grade standarts and growing the sensor-network to provide a more comprehensive assessment of flood-impacts, air and water quality in the Corpus Christi Bay Region. This study was part of an NSF planning grant that successfully led to securing a $2.5 million NSF Grant to grow this socio-technical sensor network from the community to the regional scale.

ACKNOWLEDGEMENTS

This research was funded by the National Science Foundation as part of their Smart & Connected Communtities Prgoram. Award Number: 2125234

The team thanks the City of Ingleside on the Bay, the Ingleside on the Bay Coastal Watch Association, and all residents participating in the community workshops.

HUMAN SUBJECT STUDY

This study was approved by the Internal Review Board (IRB) of the University of Texas at Arlington, IRB Protocol 2021-0817.2.

REFERENCES

Anthopoulos, L. G. (2015) ‘Understanding the smart city domain: A literature review’, *Transforming city governments for successful smart cities*, pp. 9–21.

Blackmon, D. (2021) *Moda Midstream: Navigating the Sea Change in American Energy Security*. Available at: https://shalemag.com/moda-midstream-navigating-the-sea-change-in-american-energy-security/.

Breuer, J., Walravens, N. and Ballon, P. (2014) ‘Beyond defining the smart city. Meeting top-down and bottom-up approaches in the middle’, *TeMA-Journal of Land Use, Mobility and Environment*.

BuckeyePartners (2020) *Buckeye Partners begins Operations at South Texas Gateway*. Available at: https://www.buckeye.com/press-releases/buckeye-partners-begins-operations-at-south-texas-gateway/.

Cardullo, P. and Kitchin, R. (2019) ‘Being a “citizen” in the smart city: up and down the scaffold of smart citizen participation in Dublin, Ireland’, *GeoJournal*, 84(1), pp. 1–13. doi:

10.1007/s10708-018-9845-8.

Chapa, S. (2019) *Feds give Cheniere Energy green light to begin commercial operations at Corpus Christi LNG*. Available at: https://www.houstonchronicle.com/business/energy/article/Feds-give-Cheniere-Energy-green-light-to-being-13655531.php.

Dameri, R. P. (2013) 'Searching for smart city definition: a comprehensive proposal', *International Journal of computers & technology*, 11(5), pp. 2544–2551.

Hunt, A. and Watkiss, P. (2011) 'Climate change impacts and adaptation in cities: A review of the literature', *Climatic Change*, 104(1), pp. 13–49. doi: 10.1007/s10584-010-9975-6.

IOBCWA (2022) *Ingleside on the Bay Coastal Watch Association*. Available at: https://www.iobcwa.org/.

Jenewein, O. and Hummel, M. A. (2021) 'Developing Climate Adaptation Pathways with Communities Impacted by Sea-Level Rise and Industrial Development', in *World Environmental and Water Resources Congress 2021*, pp. 888–900. doi: 10.1061/9780784483466.081.

Kopackova, H. and Libalova, P. (2017) 'Smart city concept as socio-technical system', in *2017 International Conference on Information and Digital Technologies (IDT)*. IEEE, pp. 198–205.

Ozanne, J. L. and Saatcioglu, B. (2008) 'Participatory Action Research', *Journal of Consumer Research*, 35(3), pp. 423–439. doi: 10.1086/586911.

POCC, P. of C. C. (2018) *Press Release: Corpus Christi Celebrates Two-year Anniversary of Lifting of Crude Export Ban*. Available at: https://portofcc.com/press-release-corpus-christi-celebrates-two-year-anniversary-of-lifting-of-crude-export-ban/.

POCC, P. of C. C. (2021a) *Army Corps of Engineers Awards Great Lakes Dredge & Dock Phase 3 Contract for Port of Corpus Christi Channel Improvement Project*. Available at: https://portofcc.com/army-corps-of-engineers-awards-great-lakes-dredge-dock-phase-3-contract-for-port-of-corpus-christi-channel-improvement-project/.

POCC, P. of C. C. (2021b) *Port of Corpus Christi Statistics*. Corpus Christi: Port of Corpus Christi. Available at: https://portofcc.com/about/financials/statistics/ (Accessed: 11 January 2021).

Ramirez, C. (2021) *Enbridge buys Moda Midstream's Ingleside facility, other assets for $3B*. Available at: https://www.caller.com/story/news/local/2021/09/07/enbridge-buys-moda-midstreams-ingleside-facility/5751101001/.

Reason, P. and Bradbury, H. (2001) 'Inquiry and participation in search of a world worthy of human aspiration', *Handbook of action research: Participative inquiry and practice*, pp. 1–14.

Su, K., Li, J. and Fu, H. (2011) 'Smart city and the applications', in *2011 international conference on electronics, communications and control (ICECC)*. IEEE, pp. 1028–1031.

US Census (2020) *Ingleside on the Bay, TX*. Available at: https://censusreporter.org/profiles/16000US4836020-ingleside-on-the-bay-tx/.