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Smart City Affordable Housing: Reimagining the Way We Live

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ABSTRACT
The unbuilt design presented here was a winner of the 2019 Sydney Alternative Housing Ideas Challenge international design competition. The solution proposes an investment corridor through Sydney's downtown that utilizes data collection systems to deploy population health initiatives. At its heart, the scheme recognizes that data is becoming as impactful on the way we configure cities as water and electricity were 100 years ago.

Individual dwelling units are designed to collect activity and biometric data and transmit this information to an on-site clinic or Living Lab. The technological capability provided by the clinic allows the housing operator to leverage institutional resources by leasing space to university centers or medical research entities. The rental rate far exceeds comparable rates for similar commercial facilities thus subsidizing the housing costs, technology upgrades, and even net zero energy construction.

The ideas here are now being touted as a way of better addressing Covid-related health issues through housing technology. Also presented here is a discussion on how such technology can be useful in creating more covid-resistant housing and strategies allowing seniors to shelter in place and resist the negative health impacts of isolation.

Introduction

The Sydney Alternative Housing Ideas Challenge asked teams to develop housing models that could be scaled and executed by the broader community. The solution presented here proposes an investment corridor through Sydney's downtown that utilizes data collection systems to create more livable neighborhoods and to deploy population health initiatives.

One generally associates the term "Smart City" with a government-driven effort to synchronize the core functions of a city through data collection and actionable analysis. Likewise, Lai et al. (2020) define the smart city as a city that employs technology and data to increase efficiencies, economic development, sustainability, and life quality for citizens in urban areas across three realms: energy, transportation, and health. We seem ever closer to the promise that Smart Cities yield. Yet, a digital divide widens the inequity experienced by marginalized communities. Impoverished and disenfranchised neighborhoods existing in the "data shadow" remain unable to align basic services with the livability and health advantages we expect from a so-called Smart City. (Leonelli et al. 2017, 191-202) Also, the Covid-19 crisis has brought the intersection of urban environments and community health to the forefront of this discussion. The Smart City must operate in a way that allows us to make headway on the great challenges of our time. Smart and connected cities have the potential to restructure the world and allow us to act critically and strategically within a society we cannot completely remake. One of the most impactful Smart City initiatives is the deployment of population health strategies.

Sensored environments have the ability to collect a wide range of biometric data. The collection and analysis of such data to deliver healthcare more affordably, affectively, and sometimes before we know we need it. (Hibbard et al. 2017, 1297-1309) Even more potent may be the impact on health, wellness, and general livability when this biometric data is aggregated with all the vast amounts of data a Smart City can collect. (Halegoua 2015, 311-316)

The scheme presented here proposes an incentivized investment corridor along George Street, one of Sydney's most vibrant mixed-use corridors. Connecting some of the city's most popular attractions, a light rail line opened on the thoroughfare in December 2019. Like the goals of Transit Oriented Development (TOD), the George Street gigabit investment corridor would prioritize gigabit reception enabling a more robust multimodal transit infrastructure. (Figure 1)

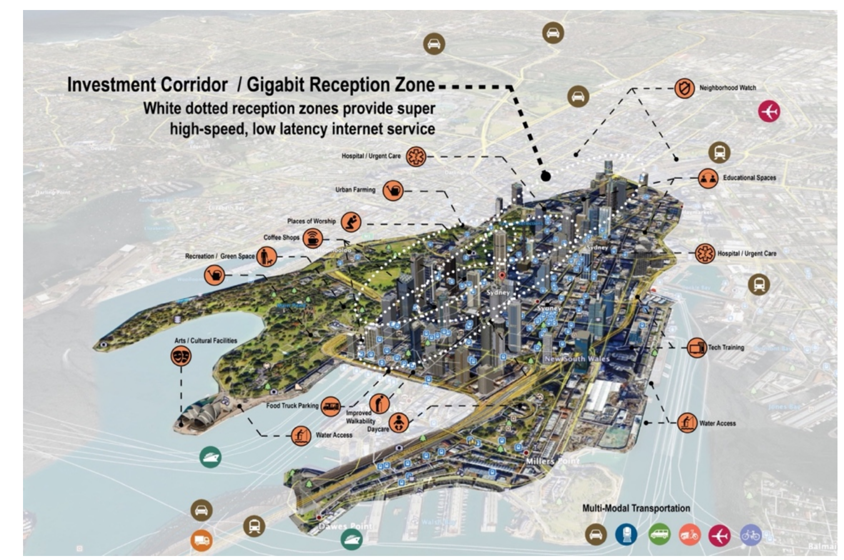

Figure 1: Sydney Alternative Housing Ideas Challenge proposal

Transit alternatives will become increasingly important as demographics shift to an older population. Many suffering from cognitive deterioration will no longer be able to drive safely. (Anstey et al. 2005, 45-65) Electronically hail or "E-hail" services such as Uber or Lyft will become increasingly important to aging drivers as they self-regulate and avoid difficult driving situations. (Molnar et al. 2013, 272-280) Robust transit options become important to the social fabric as well.

The project attempts to create lifelong neighborhoods, those that allow one to thrive at all stages of life. (Ball 2012) They incorporate great parks, great schools, access to multi-modal transit, jobs, cultural districts, and all the amenities needed in later life. Supportive components of a community where one could live their entire life include connectivity, pedestrian access and transit, neighborhood retail and services, diversity of dwelling types, healthy living, and social interaction. (Keys et al. 2014, 117-130) While every city is looking at how high-speed internet and connected services can increase quality the quality of life for its citizens, affordable dignified housing that is able to leverage this connectivity is becoming increasingly elusive for many. In 2018 Sydney was ranked second worst in urban housing affordability. Its housing prices were 13 times higher than the median income; only Hong Kong was worse. (Cox and Pavletich 2018) There is a need to re-examine both land use and financing regulations to create a downtown that is healthy, vibrant, and accessible to all people. The notion of a lifelong neighborhood, as it is presented here, offers a vision for intergenerational living and the support networks that come along with it.

Problem Statement

One of the fundamental principles of the Sydney solution presented here is monetizing the collection of activity and biometric data. This is not accomplished simply by selling the data to commercial enterprises. Although, today there is little data that one produces that is not bought and sold. In fact, it is argued that the commodification of our data may be the inevitable next step in the growth of the Internet of Things and the most efficient way to spread the wealth created from digital technologies. (Molina et al. 2019) Rather, individual dwelling units are designed to collect activity and biometric data and to transmit this information to an on-site clinic or Living Lab. These sensor-rich environments are able to collect human vital signs, physical activity, environmental conditions, and pharmaceutical regiments. This data can be collected and analyzed to deploy population health strategies. The technological capability provided by the clinic allows the housing operator to leverage institutional resources by leasing space to university research centers or medical research entities. The rental rate far exceeds comparable rates for similar commercial facilities thus subsidizing the housing costs, technology upgrades, and even net zero energy construction. The ground floor Living Lab will collect data not only on willing residents of the housing complex but also that of off-site residents as well. The facility serves as a community amenity able to collect data on a broad section of the neighborhood. Synchronized with like facilities along the George Street gigabit investment corridor, the data is able to be aggregated for implementing population health strategies. Population Health is defined as the health outcomes of a group of individuals, including the distribution of such outcomes within the group. (Kindig 2007, 139-161)

Data privacy is one of the most critical and debated subjects surrounding such technologies. Data privacy laws in Australia vary widely from HIPPA laws in the US where all residents are provided universal health care. The systems here assume data is only collected on residents that volunteer to engage in the building's programs. However, even permission to use de-identified data would be extremely useful for population health initiatives. In fact, the scheme assumes many residents living in sensored units may decline to participate in data collection programs. The model is designed to be plug-and-play. Occupants can opt out of such collection but tap into the existing infrastructure at a later date if they experience changes to their lifestyle or health. One of the most critical health markers is activity tracking accomplished by motion sensors or accelerometers in the floor. Physical activity is one of the most telling indicators of health. Activity trackers detect falls and monitor movements throughout a living unit and also a community. (Evenson and Furberg 2015, 159) One is able to track whether an elderly patient has fallen or has gone into the bathroom and not come out for several hours. Caregivers are alerted when dementia patients susceptible to confusion leave their apartment or the building complex. The transition to population health strategies enabled by Smart Cities relies on the aggregation of patterns extracted from vast amounts of data.

Other data collecting technologies include sleep sensors, smart mirrors, color-adjusted LED lighting, smart toilets, and automated medicine dispensers. One metric the team focused on more comprehensively was gait analysis.

Methodology

The pattern of one's gait, the characteristics of how one walks, is entirely unique. (Kale et al. 2003) Several factors determine the individuality of gait: body shape and size, posture, and kinesiology. Gait can also be influenced by outside factors such as floor treatment, shoe style, ground slope, moisture, etc. (Lee and Grimson 2002) Gait analysis can be used for identification, tracking, and surveillance. It is also widely used in athletic training and sports medicine. A broadening field of gait analysis is in the clinical environment where variation in stride can predict mental impairments. In the case of such diseases as Alzheimer's and Parkinson's, these physical markers can sometimes present themselves even before neuropsychological tests. (Stone et al. 2014) Typically gait data is collected through worn sensors or 3D cameras in a clinical environment. Subjects are aware they are being observed and cannot help but allow this knowledge to impact their kinesiology. Involuntary changes in body are common when one knows they are being watched. Gait is altered, posture improved, even blood pressure can rise. (Owens et al. 1998, 743-748) The shift in gait analysis presented here moves the sensing technology to the floor assembly, unobtrusively monitoring users with little interaction. The smart floor designed here, is able to collect data over a long period of time and throughout the phases of a 24-hour cycle providing a much richer data set. Similar approaches have been used in sensor-rich shoes fitted with devices that collect data on pressure, speed, rhythm, etc. (Bamberg et al. 2008, 413-423) The potential of floor-embedded sensors is that it synchronizes holistically with other health-monitoring technologies deployed in the housing unit.

One of the fundamental components of the Sydney scheme is gait analysis. Sensors in the floor are able to provide remote detection of falls, the leading cause of injury-related deaths among people 65 and older. (Burns and Kakara 2018, 509-514) Such remote monitoring has always been important in the caregiving environment but has been brought to the forefront as critical in the wake of Covid-related lock-down and isolation. The sensors are not only able to detect falls but also limp, shuffling, and a range of gait characteristics. A widening stance, shuffling of feet, or "magnetic" gait is often associated with hydrocephalous, a form of dementia. (Pirker and Katzenschlager 2017, 81-95) Gait patterns related to the ball of the foot striking close to the timing of the heel is a potential sign of neuropathy, a symptom of diabetes. (Wuehr et al. 2014, 852-858) Also, the detection of "toe-walking" and cyclical roaming in learning environments can be indicators of autism. (Barrow et al. 2011, 619-621) The identification of autism in children before language skills have developed would allow for early treatment and intervention. At two-hundred readings per second, the sensors are also able to detect muscle tremor. The implication is that this "smart floor" assembly could be used to detect symptoms of early onset Parkinson's and Alzheimer's disease. The team is currently working with computer scientists and medical researchers to explore the potential for such a system to predict and even prevent falls.

The passive collection and analysis of gait data over time can provide insights into why falls occur. Such insights can allow caregivers to intervene before a serious fall occurs. Perhaps the culprit is furniture arrangement or issues of hoarding, maybe pronounced limp can be tied to the day after a playdate with grandchildren, aligns with changes in a medicine regime, or simply variations in humidity. One strategy for prevention is understanding the activity and patterns that could cause falls, another is to more actively intervene. The team is working with a Parkinson's and Movement Disorder Center on the issue of gait initiation failure. This is an occurrence in Parkinson's patients who suffer a "freezing" of their gait. For some reason their mind is unable to properly assemble the complex motor skills needed to continue walking and the patient falls. (Vercruysse et al. 2012, 1644-1651) Sensors recognizing that gait initiation failure is about to occur are able to instantaneously send a haptic vibration to a wristband or sock to assist the subject in being aware this event is about to occur and helping them to work through it.

The gait data collected from such sensors is not significantly different from that of worn sensors in a human performance lab, however, they are a fraction of the cost. Also, unlike a worn product like an Apple Watch or Fitbit, these sensors act in the background of our lives; embedded in the walls and floor assemblies. There is no need for training, logging steps, or remembering to turn the system on. Also, the data collection is capable of operating 24 hours a day, 7 days a week. Currently, Parkinson's and Alzheimer's patients would need to make an appointment at a performance lab to have such a gait analysis performed. Even then, the subject's gait is often influenced by the recognition that their every movement is being recorded. The embedded systems described here can be opted out of and never engaged, or it can be turned on to collect data in the event of a fall or deteriorating health. It also works for a demographic that may not have the ability to operate smart phones and smart watches or lack the desire to log steps or heel strikes online. A simple prototype unit has been constructed that utilizes simple accelerometers and strain gauges to record heel strike. (Figure 2) The system has been recalibrated from large infrastructure monitoring to detect and identify sensor signals associated with a person moving about a living space.

Figure 2: Completed prototype

The node-based processing minimizes wireless bandwidth communications and enables dense sensorization of the platform. Ten three-axis accelerometers in a plastic casing were screwed into the face of joists at approximately 1/3 span. Forty strain gauges were attached with adhesive to the face of joists at approximately midspan throughout the joists of the floor assembly. All sensors are operated by rechargeable battery power. The sensors were procured from Civionics, Inc., a company whose core technology is licensed from the University of Michigan and relates to the intelligent acquisition and processing of sensor data on wireless nodes. The company's Percev product line provides end-to-end wireless sensor systems. The system features both node- and cloud-based analytics, a web-based dashboard, user configurable statistical over-sampling, user-definable virtual channels, user configurable alerts on all channels, and the ability to embed user-developed code directly in the node. This innovation allows for the system to be realistically deployed at scale. For example, to sample all channels at 1,000 HZ and transmit all of these data to the cloud would require on the order of 1.0 Mbps, with most of the data not being of interest. By using on-node processing, one can send a small window of data around a specific event of interest, such as a fall or gait anomaly, thereby cutting the data transmission rates by one or two orders of magnitude while maintaining all data of interest and increasing battery life significantly. The construction simulates a wood joist structure with crawl space but would be just as effective in concrete or steel structures. Data is collected at each wireless sensor location and sent to the cloud server where it can be aggregated and analyzed. Shifting the care and monitoring that occurs in assisted living facilities to the home and also expanding the possibility of remote monitoring, something that has been revealed to be of critical importance as communities grapple with the vulnerabilities associated with Covid-19. The "smart home" monitoring approach allows for residents to age-in-place longer and at a lower cost than the existing system of Continuing Care Retirement Communities (CCRC).

Conclusion

The potential benefits of the Smart City are clear. Vast literature exists on the impacts of data collection systems on energy usage, safety, communication, and transportation in a city. Here we explore the health benefits presented by the smart city. If we could know that an elderly resident has had limited sleep, impaired reflexes, pronounced limp, and is dangerously dehydrated, one can calculate the probability of a fall. That data can be referenced against environmental data: freezing temperatures and a light rain, high humidity, and high particulate matter in the air. These data sets may allow us to predict that this elderly gentleman has a 99% chance of falling that day. Now imagine that these sensors are imbedded throughout a housing complex with 200 housing units or throughout a community of 10,000 housing units and that some minute fraction has been identified as having a high probability of falling. Identifying those 100 citizens is extremely powerful. Aggregation of such data, even with the subject de-identified, can be useful. Gait markers identifying clusters of diabetes may indicate a food desert or locate areas of a city that have poor walkability, sidewalks in disrepair, or little access to preventative healthcare. This is the potential of a data-synchronized lifelong neighborhood, an equitable deployment of population health initiatives. Finally, it cannot be stressed enough that the monitoring technology presented here is secondary to health and wellbeing. (Colistra 2018) Primary to health and wellbeing is the safety and security one finds in diverse and vibrant neighborhoods, those that nurture social connectivity and interaction. This is the critical point that must not be lost when espousing the advantages of synchronized smart cities. What makes a great city is the diverse, mixed-use, and grittiness of the urban experience. (Jacobs 1964)

We should not allow cities to become so efficient and automated that we eliminate chance encounters on the street or disincentivize one from taking the "long way" home through a park. While the Sydney proposal was created just before the Covid pandemic, the events of 2020 have reprioritized the need to make cities more livable, sustainable, and health-centered. The principles of Smart Cities align with the necessary changes in urban infrastructure that can create more socially just environments where all citizens can thrive.

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