Smart Cities:
Population Health and the Evolution of Housing

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SCHOOL OF ARCHITECTURE & DESIGN
The University of Kansas

1. Project Name:

Smart Cities: Population Health and the Evolution of Housing

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4. Briefly describe project:

We have completed the construction of a residential framing mock-up and typical residential floor system that is able to collect data on heel strike. Utilizing accelerometers and strain gauges, we are working with a multidisciplinary group of researchers to see if the data can be used to monitor activity, detect falls, limp, muscle tremor, dragging of feet, and balance issues. We believe this data can also be used for more advanced gait analysis which can identify and predict such conditions as diabetic neuropathy, Alzheimer's and Parkinson's disease, and other forms of dementia.

5. Descriptive narrative:

The following paper was presented at the IEEE Smart Cities Conference in Kansas City in September 2018.

The Evolving Architecture of Smart Cities

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***Abstract*— This paper will present research being conducted to develop housing models that leverage data collection for use in Population Health strategies. We are currently developing a multifamily prototype unit that demonstrates best practices in creating livable communities within Smart Cities. We are also investigating prefabricated construction methodologies that will be utilized to bring these models to scale.**

Gigabit networks allow Smart Cites to collect and analyze vast amounts of data. This data is like a new kind of natural resource; one that will have as much impact on the way we plan cities as water and electricity did one hundred years ago. (KCUR, 2017)

Sensors embedded in the built environment are able to collect such environmental health information as Human Vital Signs, Physical Activity, Environmental Conditions, Pharmaceutical Regiments

Population Health strategies utilize the collection and analysis of such data to deliver health care more affordably, effectively, and sometimes before we know we need it. This is the allows Smart Cities to evolve into Responsive Cities. Some of the more advanced technologies we are investigating include: Motion Sensors/Fall Detection, Gait-Analysis, Automated LED Smart-Spectrum Lighting, Smart Mirrors, Smart Toilets, Sleep Sensors, and Automated Medicine Dispensers.

Keywords— Smart Cities, housing, prefabrication, biometric data

I. Introduction

Google Fiber announced that it was coming to Kansas City in 2012. (Loria, 2012) This would be only the second gigabit network installation in the United States after Chattanooga in 2010. (Wyatt, 2014) A robust tech startup ecosystem has flourished with the potential advantage that comes with “unlimited bandwidth.” Several symposia and summits have been held exploring the implications of ubiquitous connectivity of the Internet of Things and Kansas City’s website boasts that it is, “the world’s most connected Smart City.” (kcmo.gov/smartcity, 2017)

While many gigabit networked cities tout their entrepreneurial friendliness and potential for economic growth, the true promise of gig-speeds may be Population Health strategies. (Gigtank, 2016) Instrumented environments have the ability to collect a wide range of biometric data. The collection and analysis of such data to deliver health care more affordably, affectively, and sometimes before we know we need it. 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) The analysis of this stacked data sets offers unlimited possibilities.

The connectivity of sensors, devices, and environment through the Internet of Things requires a re-examination of the role that architects and planners can play in shaping cities that are data-driven. In particular, the housing unit; its design, fabrication, delivery, and maintenance must leverage instrumentation that can allow all citizens to connect and participate in the Smart City.

II. Moving from Smart to Responsive Cities

There exist as many definitions for Smart Cites as there have been Smart City conferences. One generally associates the term with a government-driven effort to synchronize the core functions of a city through data collection and actionable analysis. Neiroti et al. have looked at 70 cities and outlined the following primary categories: natural resources and energy, transport and mobility, buildings, living, government, economy, and people. (Neirotti et al., 2014)

The Smart City movement has the potential to improve the lives of billions of people living in urban environments on this planet. Perhaps seen as a more globalized and systematized approach to Smart Growth initiatives of the 1990’s, Smart City proponents argue that coordinated and connected systems will improve the livability while dramatically reducing resource consumption.

We seem ever closer to the promise of driverless cars, drone deliveries, and stylized utopian urbanscapes. And yet, the digital divide continues to leave marginalized communities behind. Impoverished and disenfranchised neighborhoods existing in the “data shadow” remain unable to align basic services with the livability we expect from a so-called Smart City. (Leonelli, S., Rappert, B. and Davies, G., 2017)

The potential exists that measuring the various components of a city and the analysis of these metrics can allow the city to respond and adapt to the needs of its inhabitants. One is reminded of the altruistic intentions of the Modernist movement and LeCorbusier’s mass produced ‘House-Machine’ of early last century. (Le Corbusier, 1931) While our expectations for housing have moved beyond notions of white box machines for living, the lasting legacy of Modernism is still the social project. 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.

The Smart City must operate in a way that allows us to make headway on the great challenges of our time: climate change, crumbling infrastructure, lack of access to clean drinking water, food insecurity, disaster response, security from terrorism, refugee shelter in areas of conflict, and homelessness. (Goodspeed, 2015)

III. The need for cities to evolve

By 2050 the global population will be nearly 10 billion people with nearly 70% of those living in urban areas. More staggering is the notion that over the next 40 years, we will construct as much urban fabric as has been built in all previous human history combined. (United Nations, 2015) Smart Cities with gigabit networks and connected services will be ubiquitous. And yet, affordable dignified housing that is able to leverage the connectivity of Smart Cities will become increasingly elusive for many. This integrated and connected vision of urbanity will not be realized unless we invent new ways of organizing our cities and fabricating our buildings.

Despite the sea change in technology all around us, we continue to construct buildings the way we did fifty years ago. Prefabrication, through optimized manufacturing processes is rarely applied to large-scale urban structure. Fabrication techniques, and particularly digital fabrication techniques, allow us to take a construction process we used to call “rough framing” and fabricate assemblies with the precision of a medical device.

These tolerances, applied to multifamily housing, allow us to activate Population Health strategies. Rising healthcare costs, an exploding aging population, demographic shifts from rural areas to urban areas, and a shortage of affordable housing make for a potent opportunity to transform the way we build urban environments. Re-imagining this data-driven built environment will require a multidisciplinary team of architects, planners, engineers, health care professionals, academic researchers, and industry partners to bring the potential of this instrumented built environment to society both equitably and at scale. These new housing models can improve the quality of life for all citizens.

IV. Shifting Demographics

Technology-rich prefabricated smart housing can also address shifting needs brought on by shifting demographics. American cities are incredibly unprepared to house the wave of Baby Boomers that are turning 65 at a rate of 10,000 per day. (Pew Research Center, 2010) The escalating cost of assisted living and health care costs associated with the aging will require us to re-think the way we deliver health and wellness services. (Pfeifer, 2016)

The housing prototype presented here shifts some of the care and monitoring that occurs in assisted living facilities to the home. This allows for residents to age-in-place longer and at a lower cost than in the existing systems of Continuing Care Retirement Communities (CCRC). The prototype assemblies presented here could also be used to retrofit existing housing stock that is inadequate in addressing the needs of ailing seniors.

V. Sensed Environments

Critical to Smart Cities will be neighborhood scale. IoT connectivity will not increase livability if social connectivity is cumbersome. Key to wellness will be the creation of Lifelong Neighborhoods. (Ball, 2012) Lifelong Neighborhood are those where one can thrive at all stages of life: great schools, great parks, walkability, efficient mass transit, access to job centers, various housing options, and proximity to senior health clinics and community centers.

The scale of housing is also critical. Sensor-enabled multifamily housing must support walkable streetscapes. Complete Streets concepts provide efficient systems of shared roadways and neighborhood-scaled streetscape. (LaPlante, 2007) To the fullest extent possible, housing for Smart Cities should be visitable and designed with adherence to Universal Design Principles.

To be most effective in its deployment Population Health strategies must provide essential new tools to healthcare providers in caring for those most vulnerable in society and linking them to the health services they need – sometimes before they even know they need them. Low Income Housing Tax Credit projects catering primarily to seniors may be a laudable target for sensor deployment. One innovative development model would collect biometric information on residents on site.

A ground floor “clinic” or Living Lab could collect data on willing residents and provide associated healthcare services. While this configuration provides various opportunities for public-private partnerships, a housing developer or housing authority could build out this medical office space and rent it to interested health providers, university medical centers and research institutions. The potential for low income projects is enormous.

Typically located in rent-depressed blighted neighborhoods, a university needing access to an aging demographic would be willing to pay above market rate rents. This leverage of institutional resources subsidizes the affordable housing and allows for more dignified and sustainable housing.

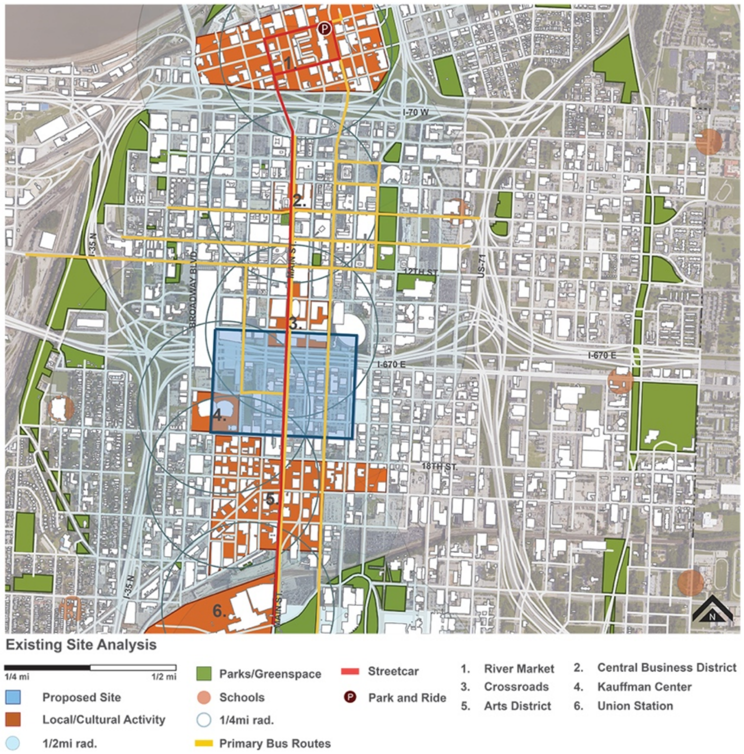

Fig. 1. Smart City Master Plan, Institute for Smart Cities, University of Kansas

Another development scenario that we had looked at was the partnering of healthcare networks with senior housing developers to provide sensor-ready units. Also, the ongoing collection of biometric data that leads to actionable health solutions may qualify for Chronic Care Management Vouchers under the Affordable Care Act.

VI. Data-Driven Housing Units

There exist several technologies that could transform the way we think about sustainable and healthy environments. Sensors embedded in the built environment are able to collect such information as human vital signs, physical activity, environmental factors, and others. Activity trackers have the ability to detect falls and monitor movements throughout a living unit and also a community. One could track whether an elderly patient has fallen or has gone into the bathroom and not come out for several hours. Someone could be alerted when dementia patients susceptible to confusion leave their apartment or the building complex.

Sleep sensors can be utilized to further monitor health. Groundbreaking work at the University of Missouri's Tiger Place uses a ballistocardiogram measuring the fluid moving in and out of the heart to monitor hours of sleep, restlessness, number of trips to the bathroom, and sleep apnea. (Rantz, et al, 2013)

Smart mirrors on the market today allow one to check the weather and watch the news. We are investigating the ability for such mirrors to track the reflexes associated with eye movement. It can even monitor skin cancer, moles, and plaque on teeth, alerting the resident or health care provider when there is a problem. Soon facial recognition software will be able to detect minute asymmetries in facial muscles that may be an indication of stroke or cardiac condition. (Andeu et al, 2016)

The smart mirror will also meter the yellowing of the eyes as we age. This yellowing of the eyes blocks the wavelengths of light that allows our bodies to re-boot our circadian rhythms each day. (Mainster, M.A. and Turner, P.L., 2013) Tied to custom-color-adjusted LED lighting, this technology will promote circadian health: the production of melatonin in the evening that helps us to sleep and cortisol in the morning to help us wake up. This circadian dysfunction could be contributing to a number of ailments one typically associates with aging: tiredness, disorientation, reduced alertness, even depression. (Tarkan, L., 2012)

Smart toilets have been written about for several years. Accessible today are units that are equipped with heated seat, sanitizing features, and music. The newest generation collect health markers. (Vanni, O. 2017) We are exploring with geriatric pharmacists the ability for a toilet to take hydration and glucose readings.

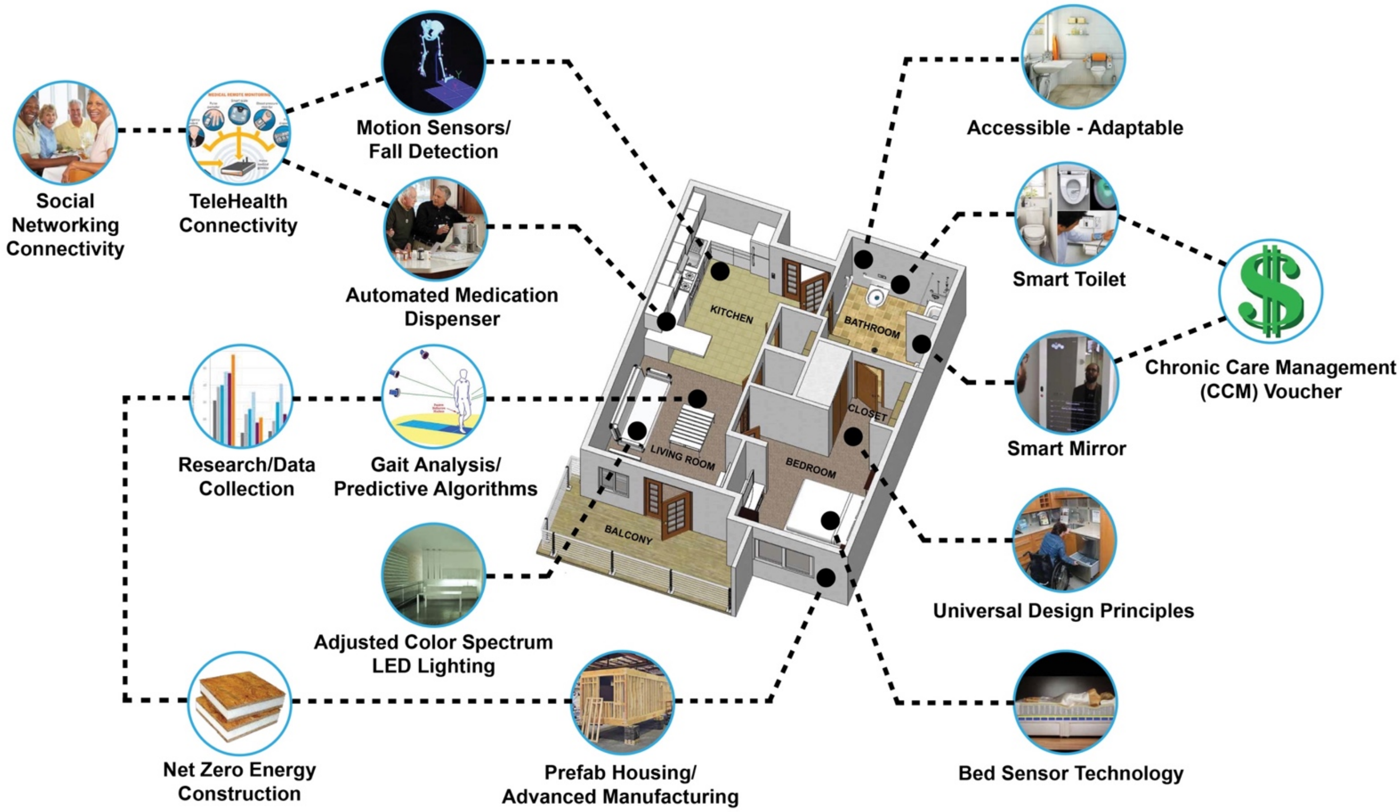

Fig. 2. Prototype "Smart" Unit, Institute for Smart Cities, University of Kansas

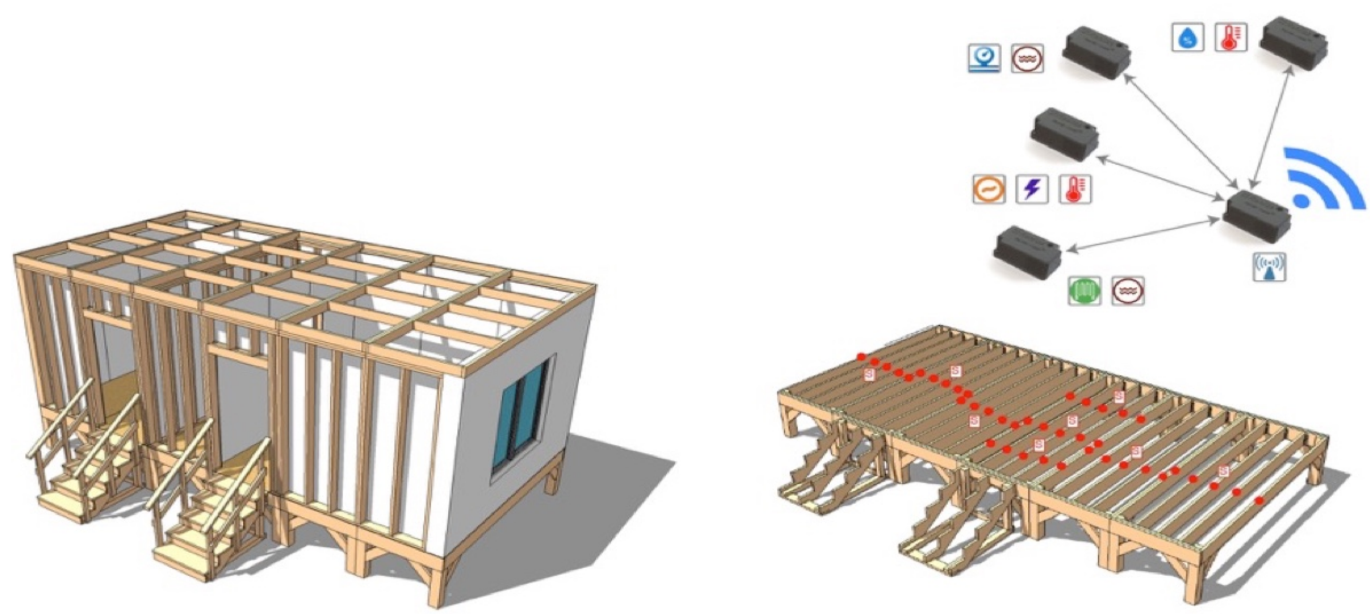

Fig. 3. Prototype "Smart" Unit Mock-up

This may provide the best anecdote for explaining the potency of a Smart City: the data could be coupled with that of an automated medicine dispenser to automatically adjust diuretic in heart medication or insulin regiments.

Perhaps the furthest we have been able to take a Smart Home feature has been gait analysis. Research grants from the American Institute of Architects and the Mozilla Gigabit Community Fund have furthered our efforts. We have installed simple accelerometers and strain gauges into a typical wood-framed residential floor and calibrated the sensors to record heel strike. At two-hundred readings per second, the data is not only able to detect a fall but it can record data patterns that may indicate a limp or stagger. The data can be fine-tuned to detect shuffling and even tremor.

The implication is that this "smart floor" could be used to detect symptoms of early onset Parkinson's and Alzheimer's disease. We are working with scientists who are developing predictive algorithms capable of processing the patterns of widening stance, often a sign of hydrocephalus, a form of dementia. We are also exploring patterns related to the ball of the foot striking close to the timing of the heel, a potential sign of neuropathy, a symptom of diabetes.

Our work with gait analysis through sensors in the floor is not nearly as accurate as the worn sensors that might be found in a human performance lab, however, they are a fraction of the cost. Also, we are not convinced they provide significantly more data than an Apple watch or a FitBit.

Again, at a fraction of the cost, sensors that act in the background of our lives: in the wall and floor assemblies, provide a remote monitoring system that is passive. It can be opted out of and never engaged. It can also be turned on to collect data in the event of a fall or other health problems. It also works for a demographic that may not have the ability to operate smart phones and smart watches or have the desire to log steps or heel strikes online.

VII. Evolving stacked datA into responsiveness

The incredible potential of a gigabit network enabled Smart City is the aggregation and analysis of this data. For example, say we know that an elderly resident has had only four hours of sleep two nights in a row. His mirror indicates that his eye tracking is off and reflexes may be impaired, gait analysis shows he is favoring his recently replaced hip, and his toilet indicates he is dangerously dehydrated.

Now, cross that data against environmental data that is being collected: the forecast calls for freezing temperatures and a light rain, high humidity, and unusually high particulate matter in the air. These data sets may allow us to predict that this elderly gentleman has a 99% chance of falling the next day.

Now imagine that these sensors are imbedded throughout a community of 10,000 housing units and that some minute fraction of that population has a 99% chance of falling the next day. Identifying those 10 – 15 citizens is extremely powerful. An alert could let them, their family, or their caregiver know that they need to take a little extra care the next day or that someone may need to assist them with running their errands. This is the potential of a data-synchronized lifelong community.

VIII. Scale Through Prefabrication

How does one bring millions of sensor-enriched affordable housing online? We believe the answer lies in prefabrication. Prefabrication allows for optimized manufacturing processes to be employed. Assembly in controlled warehouses provides for more reliable and safer working conditions. (Smith et al, 2017) Prefabricated assemblies can also be utilized to adapt existing housing stock into more connected applications.

Utilizing robotic assembly, the construction phase we now refer to as "rough-framing" will achieve tolerances that allow the housing unit to achieve the precision more appropriate to a medical device. Also, energy efficient features such as air-tight construction and high performance building systems enabling net-zero energy usage can be integrated before the assembly arrives at the building site.

Prefabrication saves money by reducing construction time, eliminating waste, and is the only viable solution to bring affordable, dignified, and connected housing to the masses.

IX. Making the Thing That Makes the Thing

The University of Kansas maintains a 65,000sf maker space out of which are run our design-build studios. The world-renown Studio 804 run by Distinguished Professor Dan Rockhill also operates out of the facility. A recent housing study conducted with fifth-year architecture students teamed University researchers with industry partners to investigate prefabricated housing techniques.

We are working with a structural building panel manufacturer to optimize the fabrication process for Passive House standards. The prefabricated system includes a traditional wood-framed structural wall, air barrier, continuous exterior insulation, nail base, water-resistive barrier, and preinstalled, air-tightened windows and doors. Students are assisting in optimizing framing table equipment to incorporate computer automated jig configurations in order to create both prototypical and custom housing solutions.

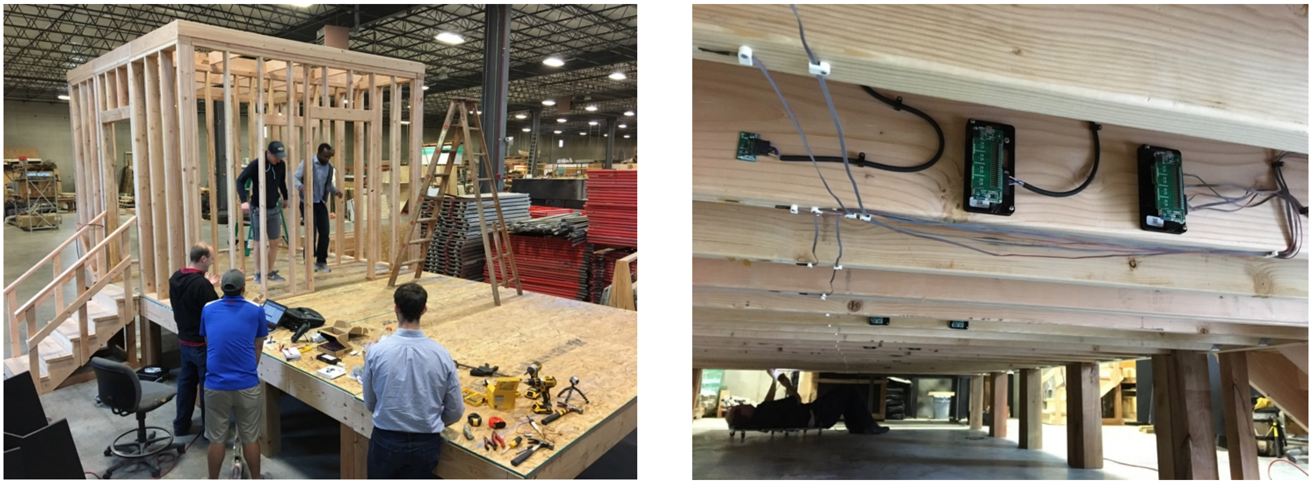

Fig. 4. Smart Floor Assembly with accelerometers and strain gauges

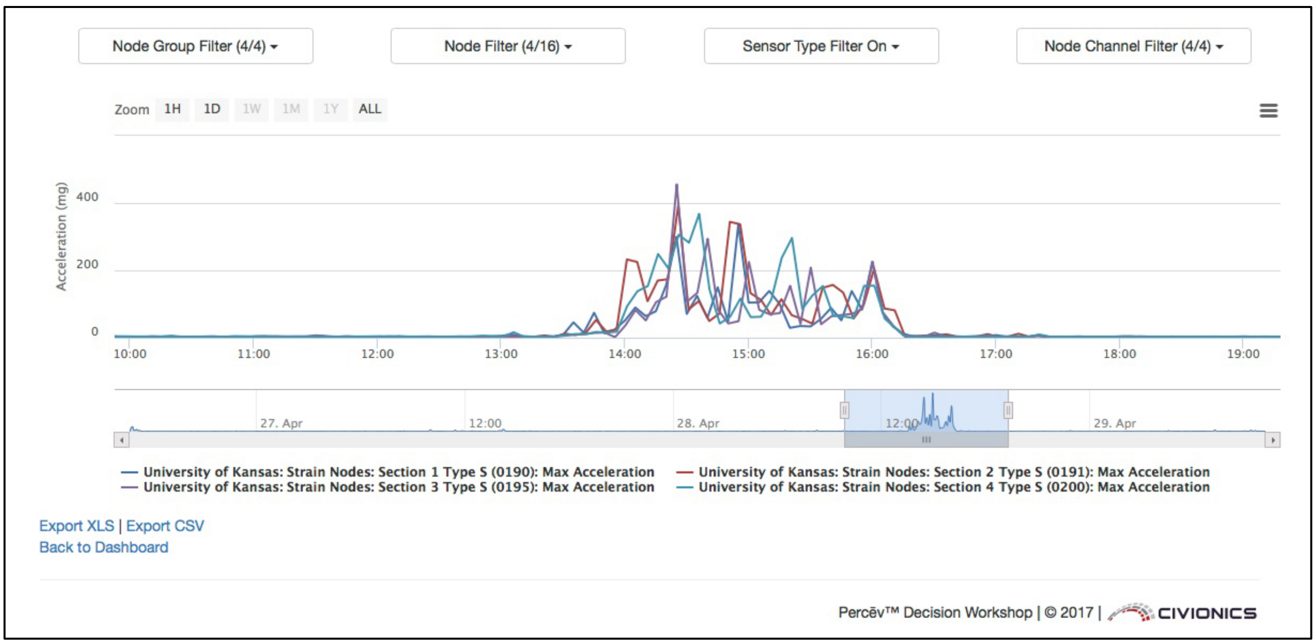

Fig. 5. Heel strike data collected for use in gait analysis

The panels can be produced in a warehouse at a fraction of the time seen in traditional site-built construction and the advanced manufacturing process will ensure quality control and reduced waste. MAMTC (Mid-American Manufacturing Technology Center) is also advising on the project. MAMTC is a not-for-profit corporation that is supported by a public and private partnership of companies, and the National Institute of Standards and Technology Manufacturing Extension Partnership (NIST MEP). The organization is a part of the US Department of Commerce and its sole purpose is to help companies realize growth in the changing global marketplace through innovation.

We are also currently working with the KU School of Engineering on a Lightweight Modular Steel Floor Systems for Rapidly Constructible and Reconfigurable Buildings. This prefabricated two-way modular system is ideal for embedding sensors. It can be fabricated in a warehouse and craned into place by two attachment points. The modules are configured from standard steel shapes that can be stacked on trucks and shipped to site. (Boadi-Danquah et al, 2017)

The self-supporting nature of the assembly allows for easy deconstruction and reconfiguration. The two-way configuration requires numerous slots to be cut at each intersection and a tack weld to hold the assembly in place. We are working with a local metals manufacturer to accomplish both the slot cuts and the

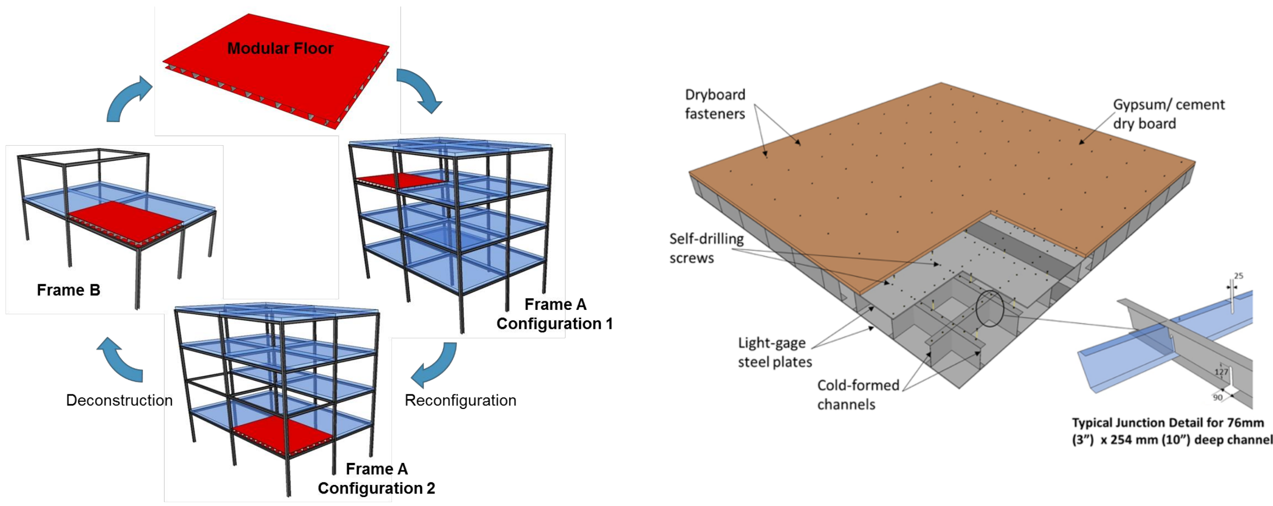

Fig. 7. Lightweight modular steel floor system for rapidly constructible and reconfigurable buildings, Fadden, M., Boadi-Danquah, E., and Robertson, B.

tack welds with robot arms. The speed and accuracy of such a process far outweighs the time and cost of accomplishing these tasks manually.

As a result of its modularity, lightweight, ease of integration of building systems, and sensing components, the smart flooring system promotes reuse and sustainability. Structures employing these modular systems are able to adapt to changing building needs and uses over time.

X. Conclusion

The notion of Population Health strategies made possible by connected urban environments will require us to reinvent the way we build buildings and organize cities. Population Health strategies link those most vulnerable in our society to the health services they need – sometimes before they even know they need it. Predictive algorithms mine biometric data collected by sensors.

Currently, there are many active (worn) sensors that exist in market products, however, sensors that exist in the background of our lives – protected in walls, floors, and ceilings - are less visible and lend themselves to being installed during the construction process. Optimized manufacturing techniques can result in prefabricated building assemblies that make up sensor-rich environments at scale. Prefabricated units configured into multifamily housing and mixed-use buildings can provide a technology infrastructure that enables plug-and-play health and wellness strategies to be prescribed, monitored, and adjusted by remote healthcare providers.

Once optimized, the housing prototypes can be adjusted to allow for the location-specific construction limitations and available labor practices. Also, energy efficient features such as air-tight construction and high performance building systems enabling net-zero energy usage can be integrated before the assembly arrives at the building site. Prefabrication saves money by reducing construction time, eliminating waste, and is the only viable solution to bring affordable, dignified, and connected housing to the masses.

Finally, it cannot be stressed enough that the health-monitoring technology presented here are secondary to health and well-being. Primary to health and well-being is the safety and security one finds in diverse and vibrant Lifelong Neighborhoods that nurture social connectivity.

Fig. 8. Smart Home mock-up construction,
Institute for Smart Cities, University of Kansas

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8. Presentations of research:

2018 “The Transformative Architecture of Smart Cities,” AIA Colorado Design + Practice Conference, Keystone, CO

2018 “Synchronized Built Environments,” Pivot: Populous Innovation Conference, Invited Speaker, Nelson-Atkins Art Museum, Kansas City, MO

2018 “Smart Cities Research Overview,” Aging 2.0 Smart Cities Symposium, Kansas City Chapter, Kansas City, MO

2018 “Remote Monitoring Innovations in Healthy Built Environments,” KC Digital Drive Health Innovation Team Seminar, Mid American Regional Council (MARC), Kansas City, MO

2018 “The Smart Cities Institute at the University of Kansas,” Lawrence Rotary, Lawrence, KS

2018 “Smart Cities Research at the University of Kansas,” Gigabit City Summit, Kansas City, MO

2018 Housing for Aging in Place, Endicott Society, University of Kansas Alumni Association, Lawrence, KS

2018 “The Evolving Architecture of Smart Cities,” 4th IEEE International Smart Cities Conference, ISC2 2018, Kansas City, MO

2018 “Housing Technology for Smart Cities,” Residential Building Design and Construction Conference, Pennsylvania State University, State College, PA

2017 “Smart Cities Research,” Universidade de Pernambuco (UPE), guest lecture via Skype, Recife, Brazil

2017 “University/Industry Collaboration Showcase,” AIA Kansas Conference, Lawrence, KS

2017 “University-Industry Collaboration Showcase,” AIA Kansas Conference, Lawrence, KS

2017 “Smart and Livable Cities Research,” Mid-America Region Council Committee on Aging, Kansas City, MO

2016 “The Future of Smart Cities and Population Health,” Cerner Health Conference, Kansas City, MO

2016 “Housing Research at the University of Kansas,” AIA Central States Conference, Manhattan, KS