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START-UP CREATION

THE SMART ECO-EFFICIENT BUILT ENVIRONMENT

SECOND EDITION

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Introduction to start-up creation for the smart ecoefficient built environment

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1.1 Sustainability challenges and entrepreneurship for a better world

About 15 years ago, Meadows et al. (2004) conducted a 30-year update of a well-known crucial study "The limits to growth" (Meadows et al., 1972), having concluded that period was nothing than a waste of time and that humanity has done very little to avoid the collapse of the Planet's environment. In 2008, Turner has also studied Meadows projection's with 30 years of real events, having concluded that the global system is on an unsustainable trajectory unless there is substantial and rapid reduction in consumptive behavior. One year later, Rockström et al. (2009) suggested an innovative approach for global sustainability defining nine interdependent planetary boundaries. They also state that humanity has already transgressed three planetary boundaries for changes to the global nitrogen cycle, rate of biodiversity loss, and above all climate change. Five years later years, Motesharrei et al. (2014) reported on a NASA-funded study that used a mathematical model to show that the overexploitation of natural resources, along with wealth inequality, can precipitate the collapse of civilizations. Khan (2015) explained in very simple words the root of problem: "earthly garbage dump is not free, but the atmospheric dump is treated free! This is because it's a global commons. So, free-riding remains the norm because of the power of major emitters." Also in 2015, the United Nations adopted the 2030 Agenda for Sustainable Development, at the heart of which were 17 Sustainable Development Goals that are based on five pillars: people, prosperity, peace, partnership, and planet (UN, 2015). Three years later, Randers et al. (2018) state that the world will not reach all Sustainable Development Goals by 2030, nor even by 2050. Stoknes and Rockström (2018) also showed a pessimistic view saying that the status quo low ambitious approach is not compatible with the ecologic limits of the Planet. Bendell (2019) recently warned about the probable social collapse: "*it is now too late to stop a future collapse of our societies because of climate change, and that we must now explore ways in which to reduce harm*". The problem is that message cannot get trough to common people the same repeated warmings by scientists also had no consequences (Kendall, 2000; Ripple et al., 2017; Cavicchioli

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et al., 2019). And probably that is why the most recent by dozens of scientists (House, 2019) also decided to endorse the movement *Extinction Rebellion.* Some optimistics like Hickel et al. (2019) argue that it is still at least theoretically possible to achieve a good life for all within planetary boundaries in poor nations by building on existing exemplary models and by adopting fairer distributive policies. However, the additional biophysical pressure that this entails at a global level requires that rich nations dramatically reduce their biophysical footprints by 40%−50%. Something that for sure will not happen, because, as the physicist Desvaux (2007) has written one decade ago, "Humans will not willingly sacrifice much of their comfortable life-styles for the greater good (especially for people in other countries) unless it is taken from them." On September 25, 2019, the IPCC released a worrying report warning about a faster sea level rising (CBS, 2019). However, the article of CBS fails to mention that there was an optimistic report like all the other previous IPCC reports. Ian *Dunlop* and David *Spratt have found* that IPCC reports tend toward reticence and caution, erring on the side of 'least drama' and downplaying the more extreme and more damaging outcomes (Spratt and Dunlop, 2018). It is rather obvious that IPCC are facing pressure from Governments to avoid releasing projections that may induce panic because panic is bad for business, and to economic growth meaning that it is bad for Governments to get reelected. But since the duty of academia is to the truth (Allot et al., 2019) not to any political agenda it's understandable why a Professor of Physics at the University of Oxford wrote in a paper published in August of 2019 the following: "*Let's get this on the table right away, without mincing words. With regard to the climate crisis, yes, it's time to panic*" (Pierrehumbert, 2019). No wonder youth movements started to show signs of rebellion against its stolen future (Hope, 2019; Bandura and Cherry, 2019; Hagedorn et al., 2019). Craig and Ruhl (2019) even mentioned that children plaintiffs are arguing to the US Court of Appeals for the Ninth Circuit that the federal government of the United States owes them, constitutionally, a stable climate, which shows that young generations are seeing their future going down the drain. And on September 20, 2019, millions of young people (and others not so young) have taken to the streets (WP, 2019). Still even if we assume that panic is bad for business, the truth is that business still plays an important part in the process because entrepreneurship for climate change could mobilize a lot of energy of young people in developed countries, which is essential in the context of young graduate's high unemployment rates that are expected to increase in the next decades due to robotization and artificial intelligence. Some projections suggest the number of students enrolled in higher education is forecast to rise from 99.4 million in 2000 to 414.2 million in 2030, an increase of 416% (UNESCO, 2015). Also entrepreneurship for climate change will especially be important for young people in poor countries. Not only because "decent work" is mentioned in the 80 SDG but also because in 2014 when Eric Schmidt and Jared Cohen were, respectively, the Chairman of Google and the Director of Google Ideas, they wrote a book entitled "*The New Digital Age: Transforming Nations, Businesses, and Our Lives.*" On it, they recalled the fact that the world has hundreds of millions of young people living in miserable conditions that can easily be radicalized to engage in terrorism. In the book, they recall the words of General Stanley McChrystal to the German magazine Der Spiegel when he said that what will defeat terrorism is not military actions but basically two things: the Rule of Law and basic living conditions like education and jobs. Sand (2019) wrote about those "not having a future" because the future is designed by elitist visionaries in rich countries: "*a tantalizing confrontation between different visions of the future and subsequently a challenge for policy-making, when pursuing a common future: On the one hand, there is the far-fetched, high-technological vision of space colonization. On the other hand, there is the what seems in contrast to be the somewhat "profane" desire for more job opportunities.*" And this constitutes not only an inequality problem but also an ethical one that may increase despair in poor countries. Also a very recent paper by Krieger and Meierrieks (2019) who studied the effect of income inequality on terrorism for a sample of 113 countries showed that it is very important to follow the aforementioned General's McChrystal advice in order to tackle terrorism. On September of 2019, several drones attacked the Abqaiq facility in Saudi Arabia, the most important oil-processing facility in the world worsening an already unstable world economy (FT, 2019), which shows the consequences of a high entangled world economy addicted to nonrenewable resources located in one of the most unstable regions in the world are especially severe for poor people. Therefore, in this context, entrepreneurship will be very important in order to mobilize the energy of young people in developed countries for a sustainability-based new economy and also to tackle the despair of young people in poor countries, which could end in terrorist actions.

1.2 Start-ups: creation dynamics and failure stigma

According to Lundvall (2017), countries and organizations promoting "experience-based" knowledge and combining it with science-based knowledge are more innovative than those that only give attention to codified knowledge, meaning that scientific production alone is not enough to unleash the innovation potential and that promoting entrepreneurship and small firms would play a critical role for economic prosperity. Also in the current context of high graduated unemployment rates that will be more dramatic in the next decades (Li et al., 2014; Roy, 2014; Sadler, 2015; Min, 2015), a context in which tacit knowledge formal education is recognized has not being enough (Agarwal and Shah, 2014) start-up creation could become a way to solve this serious problem. The paramount importance of entrepreneurs (and entrepreneurship) for economic development is mainly associated with the theoretical work of Joseph Schumpeter (1934). According to this economist, entrepreneurs are key to for the process of industrial mutation "*that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one.*" For Schumpeter, innovations are disruptions that emanate from a pathological behavior, a social deviance from norms, from daring entrepreneurs (Louçã, 2014). Start-up creation is the most distinctive feature of the entrepreneurial knowledge-based economy. Start-up creation is especially important in the current knowledge-based economy in which knowledge production is shifting from universities to highly flexible multidisciplinary teams (Hsu et al., 2014). Despite the fact that some still believe that in the next years universities will continue to be the major sources of knowledge generation, the truth is that its (indirect) role on the technology transfer process by providing highly qualified engineers to industry (as they did in the past) will no longer be considered enough. The interactions between universities, government, and industry (triple helix model) are and will be crucial for the development of the knowledge-based economy. Astebro et al. (2012) reviewed three case studies known for their high percentage of student alumni that start new businesses. This included the case of MIT and two others from Swedish universities (Halmstad and Chalmers). These authors state that the MIT is a unique case that is very hard to replicate because it combines an entrepreneurial culture with cutting-edge research and a research budget that exceeds one billion dollars. The MIT exceptionality for spinoff creation was also recently highlighted by Roberts (2014). Astebro et al. (2012) pointed out the success of Chalmers surrogate entrepreneur concept. When a student is chosen/hired specifically to develop the new venture. The reason for that has to do with the fact that the surrogate entrepreneur will add not only new entrepreneurial competence but also new network capability. This concept is based on a three-part division ownership rights. The university is entitled to one-third, the inventor to another third, and the remaining third to the surrogate entrepreneur. Lundqvist (2014) analyzed a total of 170 ventures, 35% were surrogate based. The results show that the surrogate ventures outperformed nonsurrogate ventures both in terms of growth and revenue. The surrogate entrepreneurship concept is therefore a virtuous one because surrogate entrepreneurs will contribute to a more balanced distribution of expertise among the start-up team members, which is known to be a start-up success factor. Teixeira and Coimbra (2014) recently showed that younger start-up members reveal higher levels of entrepreneurial spirit and entrepreneurial capabilities, being in a better position to internationalize earlier than older members. It is worth mentioning that the average start-up member funded by the Silicon Valley Y Combinator is around 29 years old. Still much more efforts are needed to bridge the gap between research and the entrepreneurial world (Stagars, 2014) in order to foster massive start-up creation. van Wilgenburg et al. (2019) recently showed that scientific output, patent activity, venture capital companies, clinical investigators, and entrepreneurship all have a significant influence on the number of start-ups per country in the field of biomed. However, those authors found that “when taking all relationships into account using the MVA analysis, it appears that scientific output is the key determinant of start-up success”. Argyropoulou et al. (2019) reviewed the European Paradox (Europe lacking the entrepreneurial capacity of the United States to transform the research excellence into innovation, growth, wealth, and jobs) and remembered the important coexistence of seven actors that are indispensable for bringing innovations to the market: competent and active customers, innovators, entrepreneurs, skilled labor, competent venture capitalists, exit markets, and industrialists. Since start-ups have an extremely high failure rate, an interesting fact is that the lack of funding is not the first cause of failure. A survey of several hundred failures showed that in 42% of the cases, the reason was the fact that the produce/service did not target a real “market need.” Ran out of cash and team problems rank the second and third in 29% and 23% of the cases (CB Insigths, 2018). Still on start-up failure, one important issue concerns failure stigma, which occurs when society views failure has a proof of the entrepreneur inability to deliver successful results, which is basically the same as expecting that every time Cristiano Ronaldo quicks, the ball the result is always a goal. Several authors claim that different cultural backgrounds in different countries help to explain how different countries have different views on the issue when compared to the American mantra "fail fast, fail often." Wilcock (2016) stated that in the United States, start-ups fail fast and the founders move on to the next opportunity, an experience considered to be positive by investors, while in the United Kingdom, a failed start-up can be a millstone around an entrepreneur's neck as they try to raise funds for future ventures. Matthias (2018) compared media reporting about failure of start-ups in Germany and the United States, noticing that US media reports more positively about failed start-ups, than the German media does. This is also confirmed by Gellman (2018), which may help to explain why in Germany entrepreneurship and disruptive innovation are consistently low, whereas the United States performs very well in these areas (Richter et al., 2018). Holland (2018) mentioned that many people who try to start businesses in Australia cannot stand the thought of failing. The same is for most Asian cultures. Peretz Lavie, the President of Technion, mentioned that his country has almost the same approach as the United States (Lavie, 2019), reporting cases of Technion students who were only successful on their 10th attempt. Nahata (2019) noticed that in countries that value experience (successful or not), previously unsuccessful serial entrepreneurs receive better deal terms than novice founders, consistent with entrepreneurial learning being an important factor in fostering future entrepreneurship. Corner et al. (2017) did not find resilience problems after venture failure, of course this must be viewed in the light of New Zealand culture because Mehwish (2018) states that resilience plays a crucial role in reentry to business and future venture success. Quek (2019) mentioned a study that shame prevents founders from openly sharing their problems, and this can be a vicious circle that further perpetuates a culture where no one wants to talk about failure and the shame associated with it becomes worse. And that is why recently some events were created, such has FailCon or Fuckup Nights, to tackle this problem. However, Funken (2018) advises that some caution must be used to avoid excessive celebration of failures suggesting an error-handling strategy.

1.3 The importance of start-ups for the smart ecoefficient built environment

Still on the innovation philia that is probably the most common feature of start-ups, it is worth remembering the words of an emeritus professor of economics at Stanford University who called the pathological impulse to push the rate of innovation to be ever faster needs a medical psychiatric designation, which could be termed the "Imelda Marcos syndrome" (Soete, 2019). That is the case of "*innovation in consumer goods* *that induce customers to migrate continuously to newer models include new product design, electronic goods manufacturers ceasing to supply essential after-sales services or spare parts for older or even the case Apple planned obsolescence of the battery life*" (Soete, 2019). But is for sure note the case of innovation in field of smart ecoefficient built environment which is a subfield of civil engineering. Civil engineering is known as an area mainly concerned with directing the great sources of power in nature for the use and convenience of man through the construction of large and public infrastructures (bridges, dams, airports, highways, tunnels, etc.) by large construction companies. Civil engineering has an important role to play, given the environmental impacts of the construction industry that will be exacerbated in the next decades due to the growth in world population, especially urban population that will almost double until 2050, increasing from approximately 3.4 billion in 2009 to 6.4 billion in 2050. Not surprisingly, estimates on urban expansion suggest that until 2030 a high probability exists (over 75%) that urban land cover will increase by 1.2 million km^2 (Seto et al., 2012). This is roughly an area equivalent in size to 20,000 American football fields every day (United Nations, 2018). Since the global construction industry consumes more raw materials (about 3000 Mt/year, almost 50% by weight) than any other economic activity, the previously mentioned urban expansion will dramatically increase that consumption (Ashby, 2015) and produce approximately 2 billion tons of waste per year (Seto et al., 2014) and about 75% of carbon emissions from global final energy use this not only will make it more difficult to reduce greenhouse gas emissions but will also put increase pressure on biodiversity loss which is crucial for humanity survival (Cavicchioli et al., 2019). It is rather obvious that in the next decades, the built environment will have worry on many climatic change—related events like sea level rise, sudden flooding, cyclones, and extreme heat waves. Be there as it may by redirecting the focus of civil engineering from construction and rehabilitation of grand infrastructures to smart ecoefficient built environment related areas and the needs of individual home users will enlarge the number of future clients. Different user problems will require different tailored solutions, and this may represent a wide market of millions of clients who may foster high-tech start-up creation. A field related to the sustainability of the built environment where start-ups may have started to gain some traction concerns carbon sequestration. It is worth remembering that 5 years ago, Amoureux et al. (2014) already have suggested that carbon dioxide should be seen as a commodity that could serve as basis for a new economic industry. Germany initiated as one of the first nations in the world a major research program in carbon dioxide capture and utilization, and between 2010 and 2016, approximately 100 million Euros have been granted for 33 collaborative research and development projects, consisting of more than 150 individual projects (Mennicken et al., 2016). The flagship programme EnCO_2re, one of the five Climate-KICs, which started in 2014 with public launch in 2016, currently looks to develop new technologies offering novel ways to use CO_2; increase awareness for CO_2 re-use; and ensure sustainability and social acceptance of materials and products by integrated socioecological research. This programme is led by Covestro AG (formerly Bayer MaterialScience AG) working with other Climate-KIC companies and university/research partners from several countries including Denmark, Sweden, the United Kingdom, France, and the Netherlands. A McKinsey & Company report estimates that carbon products—especially in concrete, plastics, fuel, and carbon fiber—could be a market worth between $800 billion US and $1.1 trillion US by 2030 (Global CO_2, 2016). XPRIZE Foundation, designed to accelerate new technologies by converting CO_2 emissions from industrial facilities into valuable and useable products, has created the US$20 million NRG COSIA Carbon XPRIZE. The competition is structured as a two-track prize, with the new technologies tested at either a coal power plant or a natural gas power plant (COSIA, 2017). It is also worth mentioning the case of the start-up "Carbon8 Aggregates," whose technology combines carbon dioxide with waste residues from municipal incinerators and energy plants to form calcium carbonate (Carbon8, 2017). Another carbon sequestration possibility encompasses using carbon dioxide generated by heavy industry to cultivate microalgae that can then be used to produce feedstock for animals and even food for humans. Photosynthetic microalgae use sunlight as their energy, water as their electron source, and CO_2 as carbon source. Contrary to other biofuels sources, microalgae have a high oil content and most importantly show an extremely rapid growth. It doubles their biomass within 24 h being the fastest growing organisms in the world. In addition its potential as CO_2 abating technology will also increase its cost–efficiency relation. The production of 1 ton of algae biomass results in avoiding 0.5 tons of CO_2 (Koller et al., 2015). Recently, it was reported that an Estonian start-up was using microscopic algae to turn CO_2 into valuable products with a technology designed to cultivate microalgae right through the harsh winters of Northern Europe, when daylight is in short supply and temperatures are generally below freezing (Pringle, 2019). Recently, carbon capture and sequestration was considered 1 of the 100 Radical Innovation Breakthroughs for the future (EC, 2019). Of course, the report suggested that carbon prices may need to rise three to six times as much to spur the adoption of carbon capture and other innovative technologies. That is the same opinion of Nobel laureate William D. Nordhaus (2017) who suggested a carbon tax as an important way to reduce emissions cost-effectively and also to strengthen incentives for research and development of technologies that will lower the cost of reducing emissions. Be there as it may, the truth is that start-ups on carbon sequestration are already getting massive funding (MIT, 2019). Another important area that may unleash a lot of business opportunities for start-ups concerns the Smart Built Environment. This includes mostly smart homes but more recently also other smart features for infrastructure monitoring. The investigation on smart homes begun in 90s with the MIT pioneering work "Smart rooms" (Pentland, 1996). De Silva et al. (2012) defined it as "*home-like environment that possesses ambient intelligence and automatic control, which allow it to respond to the behavior of residents and provide them with various facilities.*" They also mention that currently there are three major application categories. The first category aims at providing services to the residents and includes smart homes that provide eldercare, smart homes that provide healthcare, and smart homes that provide childcare. The second category aimed at storing and retrieving of multimedia captured within the smart home, in different levels from photos to experiences, and the third is about surveillance, where the data captured in the environment are processed to obtain information that can help to raise alarms, in order to protect the home and the residents from burglaries, theft, and natural disasters like flood, etc. The concept "smart buildings" has been associated with a more recent and advanced grouping that integrates and accounts for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at its core, in order to meet the drivers for building progression: energy and efficiency, longevity, and comfort and satisfaction. Apart from the discussion between the intelligent/smart/sentient concepts, it is important to retain that the overall objective relies on the development of housing to be healthier, safer, and comfortable. In the next years, three major disruptive drivers (big data/Internet of Things (IoT)/cloud computing) will radically change smart homes. The data generated from thousands of home sensors and home appliances that are able to connect to each other, to the send data, and to be managed from cloud networks services will boost smart homes advantages (Kirkham et al., 2014). Thanks to IoT, the largest software companies will make a shift to the physical world as did Google that recently acquired a company producing thermostats to enter its trademarks in the smart home world (Borgia, 2014). This highlights the importance of building energy efficiency. An importance that is also shared by some works on the IoT area (Moreno et al., 2014) and which is special needs to address ambitious energy consumption targets like for instance the Zürich 2000 Watt Society. More on the role of energy-efficient built environment to European smart cities can be found in Kylili and Fokaides (2015). Smart homes will be able to assess occupant's satisfaction, which is one of the main shortcomings of built environment. Even in green buildings that surprisingly are not so occupant friendly as previously alleged. In a postoccupancy study of a LEED Platinum building, some occupants mentioned thermal discomfort (Hua et al., 2014). The assessment of the occupant's feedback in smart homes will trigger interactive actions to adapt homes performance accordingly. This leap is from neutral comfort (absence of discomfort) into a new one in which the wellbeing of occupants is at the heart of the smart home concept. Also older people constitute an important group of users with special needs that could benefit from smart homes features. Besides, in the next decades, this group will increase dramatically. The global population of people over the age of 65 is expected to more than double from 375 million in 1990 to 761 million by 2025, and by 2040, it is expected to reach 1300 million. Between 2100 and 2300, the proportion of the world population in the 65 or over age group (the retirement age in most countries) is estimated to increase by 24%−32%, and the 80 or over age group will double from 8.5% to 17%. Some studies found out that elderly people would prefer to live in their own house rather than in hospitals, which means that is important that homes can be studied and adapted to enhance elderly user's satisfaction. For instance, home sensors can be used to detect air pollutants like volatile organic compounds (VOC) and trigger ventilation to reduce its concentration. They can also be used to balance daylight exposure and artificial light in order to guarantee enough light to maintain circadian rhythmicity or else to warn elderly occupants on heat waves and high UV exposure. More importantly, the sensors of the networked infrastructure in smart cities collect enormous data, which are then available for entrepreneurs to make use of them in new and innovative ways (Kummitha, 2019). In this context, the deployment of smartphones for civil engineering has been gaining traction for monitoring several infrastructure systems (Alavi and Buttlar, 2019). This is because smartphones are equipped with various low cost smart sensors such as accelerometers, global positioning system, gyroscopes, and cameras along with on-board storage, computing, and communication capabilities and thus can become an intelligent, scalable, autonomous, and low-cost component of the next generation civil infrastructure monitoring systems (bridges, highways, environmental noise, etc) in smart cities. Lastly, it is important to emphasize that since smart cities are able to put together talent, knowledge, and capital, they are especially dedicated to support entrepreneurs (Florida et al., 2020) as long as they remember that the interests of citizens must not be forgotten (Engelbert et al., 2019).

1.4 Outline of the book

This book provides an updated state-of-the-art review on the start-up creation for the Smart Built Environment.

The first part encompasses an overview on business plans, start-up financing, and intellectual property (Chapters 2−5).

Chapter 2 focuses on the nature of business-planning activities from an engineering entrepreneurial perspective. After discussing the unique characteristics and challenges of technology-driven business environments, which are typically the business playground for engineering professionals, the chapter focuses on describing the two key components of the business planning process.

Chapter 3 addresses the concept of the Lean Startup approach as a way of reducing the risk and enhancing the chances for success by validating the products and services in the market with customers before launching it in full scale. The main point is to develop a minimum viable product that can be tested by potential customers and then pivot the idea if necessary around these customer evaluations.

Chapter 4 discusses the pro and cons of different start-up financing options. Stock investors collect repayment only when the start-up is acquired or goes public, but entrepreneurs cede some control of the start-up to stockholders. Hybrid options like convertible debt provide a temporary solution to some financing problems.

Chapter 5 provides an overview of different forms of intellectual property and of the ways it is protected at global, regional, and national levels. It discusses the development of the intellectual property right protection in different historical and geographical contexts. International regulatory framework of intellectual property right protection is discussed with the special focus on Europe and on the European Union. The impact of current technological developments on the intellectual property protection is addressed.

Carbon sequestration technologies for ecoefficient buildings are the subject of Part II (Chapters 6−8).

Chapter 6 discusses in detail possibility of CO_2 sequestration by cement-based materials through accelerated carbonation curing. Reaction mechanisms, laboratory processes, and resulting performance of carbonation curing have been comprehensively discussed and reviewed based on available literature. The chapter also discusses challenges faced by ACC for industrial implementation and future scope of research on carbonation curing.

Chapter 7 discloses results of an investigation concerning the carbon sequestration performance of fly ash/waste glass alkaline-based mortars with recycled aggregates reinforced by hemp fibers.

Chapter 8 highlights the potential of photobioreactor façades through the microalgae and built environment interaction from a biosymbiotic perspective comprising the technical background on biochemistry, design, and application.

The third part encompasses algorithms, big data, and IoT for smart buildings (Chapters 9−12).

Chapter 9 analyzes the Affective IoT, smart homes, ambient intelligence, affective computing, BIM, smart and interactive buildings, and smart building systems. There is also a description of the affective BIM4Ren, which is currently under development by the authors of this chapter.

Chapter 10 is concerned with the implementation in a case study of a cost-effective, low-power, and long-range IoT device for real-time monitoring. Due to the great impact that air leakages have on buildings energy demand, this variable has been taken as object of monitoring.

Chapter 11 investigates the opportunity covered by innovative algorithms to enhance buildings' energy efficiency and occupants' comfort. This chapter covers an exhaustive overview of the current development trends, analyzing both the relevant scientific literature and the commercialized solutions currently available on the market.

In Chapter 12, several key limitations in existing approaches of thermal comfort sensing are discussed, such as lacking actionable human data in comfort prediction, intrusiveness, and privacy concerns resulted from conventional data collection methods.

The chapter summarizes recent research whereby human physiological data are collected from wearable devices (e.g., smart watches and electroencephalogram headset) and infrared thermal cameras.

Finally the fourth part (Chapters 13−15) deals with smartphone applications for infrastructure monitoring algorithms.

Chapter 13 introduces the advent of smartphones as an SHM technology and describes crowd/citizen engagement into an SHM framework. The chapter concludes with the state-of-the-art vision for smartphone usage in SHM, near future trends, and finally long-term research directions.

Chapter 14 reviews smartphone applications for bridge monitoring and data analysis in laboratory environments and in situ. A case study presenting a short-term monitoring of a suspension bridge is included to demonstrate capabilities of smartphones collecting ultrahigh videos, from which accurate dynamic response is derived.

Chapter 15 offers an overview of several methods designed to monitor noise pollution in urban areas, taking advantage of the increasing popularity of smartphones and advancement of their technological capabilities, thus, using the mobile crowdsensing method, to create cities' noise maps in a more easy and intuitive way.

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