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From Compact City to Smart City: A Sustainability Science & Synergy Perspective

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Abstract: This brief conceptual paper contributes a sustainability theoretic perspective of an urbanization paradigm known as Compact City. Compact City is an urban planning and development concept which promotes relatively high population density associated with an integrated and mixed-use land district. It is enabled by transit-oriented development and results in low transport-related energy consumption and reduced the GHG (Greenhouse Gases) pollution. Compact City conserves the natural capital of land mass and subscribes to the strong sustainability ethics. ICT (Information and Communications Technology) could be deployed to optimize the Compact City operations by first tackling some of the development problems associated with Compact City and also unleashing new urban innovations and functionalities to achieve sustainable urbanization. The paper suggests and elucidates several general systemic synergies archetypes such as co-benefits, cascading, ICT infrastructure reuse, etc., which could be leveraged to facilitate the emergence of compact green smart and resilient city. These archetypes are solutions to the Compact City paradigm thus conductive to the development of a Sustainability Science of Compact City.

Key words: Compact City, synergies, co-benefits, cascading, reuse, Sustainability Science.

1. Introduction: The Universal Trend of Urbanization

Currently, over half of the world's population lives in urban areas, and that number is expected to continue to grow. The United Nations predicts that by 2050 over two-thirds of people will live in cities (Fig. 1). Such a major shift (almost 1.5 million people a week) is bound to have significant and even irreversible consequences in terms of the demands on natural capitals. Are people prepared for such a momentous change in the way the world's population lives and the resultant interaction with the natural environment taking place at city level?

This communication suggests that to fully exploit the many benefits of urbanization and its resultant demand on the natural environment, a fundamental paradigm is necessary: the idea of using technology and social organization to substitute and to optimize natural capitals during the urbanization process. This is to protect and preserve natural capitals such as land mass and air quality (i.e. generally both sources and sinks) and to create and sustain economical and social development to achieve sustainable urbanization.

Authors illustrate this using Hong Kong as a Compact City as example. Authors will start by reviewing the major paradigms of sustainability, the benefits and disadvantages of Compact City, the definition of a Smart City and conclude with a conceptual framework of Sustainability Science how to facilitate the move from a Compact City to a CSGR (Compact Smart Green Resilient) City.

2. Major Paradigms of Sustainability

In Our Common Future, commonly referred to as the Brundtland Report [1], the definition of sustainable development was first proposed as "Sustainable development is development that meets the needs of the present without compromising the ability of future

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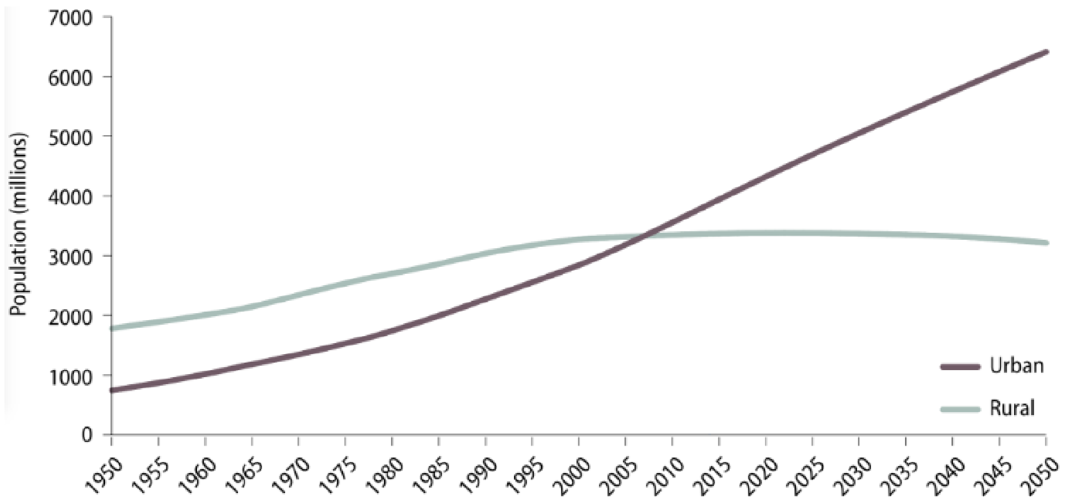

Fig. 1 The rising urban population [2].

generations to meet their own needs". It contains within it a key observation relevant to author's discussion of urbanization: the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. In other words, with advanced physical and social technologies, authors could minimize their impacts to the environment and make inter-generational sustainability more likely. In the context of urbanization, authors are interested to explore how technology could be harnessed to sustain the urbanization process. Given the fact that authors are living within a (closed) biosphere [3] which is not growing, the various life-supporting sources and sinks functions of authors' environment, if not managed properly, are expected to be depleting. In this vein, could technology come to the rescue?

Economists have formulated the sustainability problem from both absolute and relative points of view [4]. The absolute perspective, otherwise known as strong sustainability postulates that authors should hand the same stock of natural capitals which authors inherit to their next generation intact, and that technology and natural capitals, viewed as production factors or inputs to their economic activities, are only complements; i.e. the two could not substitute each other. An example follows: the mastery of fish farming or aquaculture could not substitute or mimic the production process associated with natural fishery, not to mention the former gives rise to a host of environmental problems. The relative perspective, otherwise known as weak sustainability postulates that the future generation only needs from the current generation the equivalent "productive potentials" of natural capitals rather than a stock of any given natural capital. In the case of crude oil, for example, what the future generation needs from the current generation is not really about how much crude oil the current generation leaves for them but the capability of generation of energy or electricity from oil. Viewed this way, technology embodied in products such as solar panels, wind turbines, could be used as a substitute of crude oil as natural capital in the anthropogenic pursuit of the economy. Running out natural capital is acceptable because technology could replicate the functionalities of the [now lost] natural capital. The dichotomy of weak vs. strong sustainability is a rather stylized representation of sustainability. In fact, they represent the extremes of a continuum of sustainability ethics. Real life sustainability policy may lie anywhere along that continuum.

3. Hong Kong as a Compact City

Hong Kong is a noted economy in Asia and the world. Its per capita GDP in 2016 according to the

International Monetary Funds stands at about 59,000 International Dollar which is in par with that of the US. It boosts 1,379 regional headquarters in 2016 (census and statistics department) and is consistently ranked as one of the top ten most competitive economy (World Economic Forum). It is one of the densest cities in the world: the average population density of built-up area is about 27,330 persons per square kilometers. The densest populated districts in 2011 were Kwun Tong (about 55,200 persons per square kilometers). In fact, all of Hong Kong's population lives on approximately 76 square kilometers of land which is merely 7 to 8% of its land area (in which about 20% of land is steep slopes of ≥ 30° in gradient hard to be used for development). It is an exemplar of a Compact City associated with a high-density development strategy. From a natural capital point of view, the Compact City paradigm conserves land (mass) as a natural capital.

3.1 What Are the Benefits and Disadvantage of Compact City?

The advantages of high-density living or development are many. First, it preserves land with conservation value such as unique biodiversity[1]. In Hong Kong, about 67% of the land area is natural landscape and more than half is designated as country parks not purposed for development. The Cullinan, Union Square Package 6 in the Kowloon MTR (Mass Transit Railway) station boosts around 270 meters high. Vertical development, enabled by state of art construction technology, economizes land masses (think of an alternative sprawling development plan which would house the same 1,000 households on flat land) thus subscribing to the strong sustainability paradigm. On the other hand, the fact that such construction technologies "amplify" the potentials of a "given" land mass could be seen as a case to use technology to substitute the natural land mass [5] and could be interpreted as weak sustainability. Compact City therefore subscribes to both strong and weak sustainability, the former because it saves natural capitals, the latter because it uses technology to substitute for land consumption otherwise necessary.

Second, the concentration and collocation of economic activities, associated with a higher population density and with better home-job balance[2] would stimulate knowledge generation and diffusion and create economic opportunities in a mixed-used community or neighborhood. This would create an "economy of density" [6] in the provision and demand for services.

Last but not least, higher population densities can create necessary threshold for mass transit alternatives to enable compact TOD (Transit-Oriented Development) [7]. The physical infrastructure (e.g. railway) connecting different high-density sites could leverage on the familiar economy of scale amortizing the costs of development across a large ridership. The so-called rail + property development model also creates values for properties along the rail line. The railway as a backbone or the "string of pearls" model enables an integration of urban, transport and environmental planning contributing to the foundation of urban sustainability. The specific urban planning requirements within each high density district such as walkability, cyclability, accessibility and permeability are beyond the scope of this paper and interested readers could consult [7] for more details.

Despite all these advantages, the concentration of concrete structures and impervious surfaces with low albedo trap the local city heat, giving rise to micro-climate such as due to UHI (Urban Heat Island) effects. In Hong Kong, the temperature summit [8] or the day time maximum temperature in the town centers could be 3 to 5 °C higher than the nearby maximum temperature readings of the Hong Kong Observatory. UHI would in turn aggregate the global

[1] Over 50 species of terrestrial mammals, 236 species of butterflies, 185 species of freshwater fish, 538 species of birds.

[2] Home-job balance would reduce travel related emissions due to lesser travel needs.

climate effects and result in higher frequency of local rainfall. The air pollution within a city would also be trapped due to the canyon effects associated with the urban geometry of high rise building and skyline. Reduced vegetation not only inhibits evapotranspiration but also stormwater absorption capacity rendering a higher likelihood of flooding. While there are not without solutions to adapt these via urban planning layout, reduction of thermal load (such as through energy efficiency initiatives to reduce energy demands) and creation of breezeways or modification of urban geometry based upon air ventilation assessment, reduction of building heights, use of suitable building materials etc., such local effects do pose a limit to compaction.

Looking forward, any sustainable development strategy based on the Compact City paradigm must be ambidextrous: on the one hand, it must proceed with climate resilient urban planning practices aiming at the mitigation and adaptation of a Compact City's negative externalities; on the other hand, new city functionalities must continually be developed upon the physical compact urban form and operations to improve quality of life, operations efficiency and to bolster economic competitiveness, migrating to the era of Smart City.

4. What Is a Smart City and What Enables It?

According to Cohen, B. [9], a city is smart in at least six aspects, namely: smart mobility, smart environment, smart economy, smart living, smart people and smart government. It relies on the deployment of an Internet or, more generally, an ICT (Information and Communication Technology) infrastructure and data from various sensors are operated upon to create values such as improved efficiencies or innovative and economic values. In particular, Dameri, R. P. and Rosenthal-Sabroux, C. [10] define the objective of "Smart City" as to leverage ICT to improve the quality of life of citizens, optimize resource usage and maintain sustainable development. Ojo, A. et al. [11] define that "Smart Cities" are urban innovation and transformation initiatives which aim to harness physical infrastructure, ICT, knowledge resources and social infrastructure (social organization and capitals) for economic regeneration, social cohesion, better city administration etc.. It is important to generalize the notion of Ojo, A. et al. [11]. Urbanization draws upon a multitude of capitals (forum for the future): not only natural capitals but also technologies, social capitals or governance to deliver a diversity of improved urban efficiency and novel values. Several examples of Smart City applications in Hong Kong leveraging/synergizing the built infrastructure and digital infrastructure are illustrated in the next section.

4.1 Synergies of Physical and Digital Infrastructure in Three Scenarios

Example 1: In Hong Kong, the DSD (Drainage Services Department) [12] is utilizing real-time sensor (digital infrastructure) to facilitate the drainage operations. Real-time water level sensors are installed at the Happy Valley Underground Stormwater Storage Scheme (the physical built flood mitigation infrastructure) which helps to control the weir crest level to ensure that the filling of the storage tank would start at the most optimal time to prevent premature or late overspill of stormwater into the storage tank. This digital information reduces the design capacity of the storage tank by as much as 30% thus minimizing the amount of excavation for construction and thus the total construction time. This example demonstrates how the ICT infrastructure could be retrofitted to amplify the capacity of the already built physical infrastructure associated with a Compact City.

Example 2: Compact City can enhance accessibility to local services. More dense neighborhoods have more access to daily service functions (convenience stores, banks, post offices, medical facilities, stations, etc.) within walking distance. Higher quality of life in turn attracts more talented people to cities and large population in turn demands more services and this sustains a growth virtuous circle.

An (digital) app which would display the arrival time (information) of a bus in a multi-modal shift transit-oriented development terminal would allow a passenger to use the idling time spent waiting for bus to do shopping in the nearby (compact) mix-use high service density neighborhood [6], contributing to the local economy. It goes without saying that a parking app operating on geo-spatial data optimizes the time searching for car park, mitigating traffic congestion and greenhouse gases emissions and increasing productivity. This app could also enables the "first mile, last mile" concept and to promote the concept of a walkable city by recommending points of interest and with the provision for pedestrians to leave feedbacks. Equipped with open CCTV surveillance data (without breaching applicable privacy regulations), such app could also be used as smart crowd management system, thus further optimizing the usability and capacity of the physical infrastructure.

Example 3: CAPCARE (City Action Platform for Climate Change & Energy Saving). This is a GIS (Geographic Information System) platform under development in Hong Kong for integrating [open] data at different granularity such as: environmental, climate data provided in a typical UCM (Urban Climatic Map), energy data obtained from a digital electricity meter and the BMS (Building Management System) at the building level, all in the context of a compact development (physical) infrastructure. This platform has the potential to do self-diagnostic and instigate self-healing (mitigation) of the operations of the stock of physical infrastructure by incentivizing behavioral changes based on objective [real time digital] data. It is estimated that it has the potential to reduce energy and carbon dioxide density from 2005 level by 40% by 2025 and 60-85% by 2030 respectively [13].

5. Conceptualizing Transition from Compact to CSGR City

The above three examples demonstrate that the deployment of ICT infrastructure and the utilization of operations data, if available, could enhance the operations efficiency of an existing built infrastructure and also optimize design capacity decision of the physical infrastructure made a long time ago.

A physical infrastructure usually has an operations life of at least half a century and once it is built, it enables and also constrains the social and economic activities with associated environmental implications to a city or a neighborhood, and its long-lasting effects should not be underestimated. With all the advantages of a Compact City, digital infrastructure and digital data could optimize and amplify the potentials and capacities of the fixed physical infrastructure in the midst of momentous urbanization. To conceptualize how to upgrade a city from Compact City to CSGR City (Fig. 2), several best practices and principles could be suggested:

(1) [Co-benefits] To optimize the combined effects of local micro-climate (e.g. urban heat island effects) and global climate change, the pursuit of both mitigation and adaptation is indispensable. Projects could be chosen and prioritized if they could both mitigate and adapt climate effects. This not only economizes project expenditure but also expedites much needed climate actions.

Urban farm is a prime example of providing the co-benefits of mitigation and adaptation (Fig. 3). It first curtails greenhouse gases emissions associated with the "food miles" produce need to travel otherwise. Due to evapotranspiration, it could also lower the temperature (by 5 °C or more) of the proximity (e.g. the rooftop) where the farm area is situated thus depressing the energy consumption for air conditioning which will further alleviate the waste heat ejected locally. Lesser impervious surfaces would also increase the water retention capability thus making the

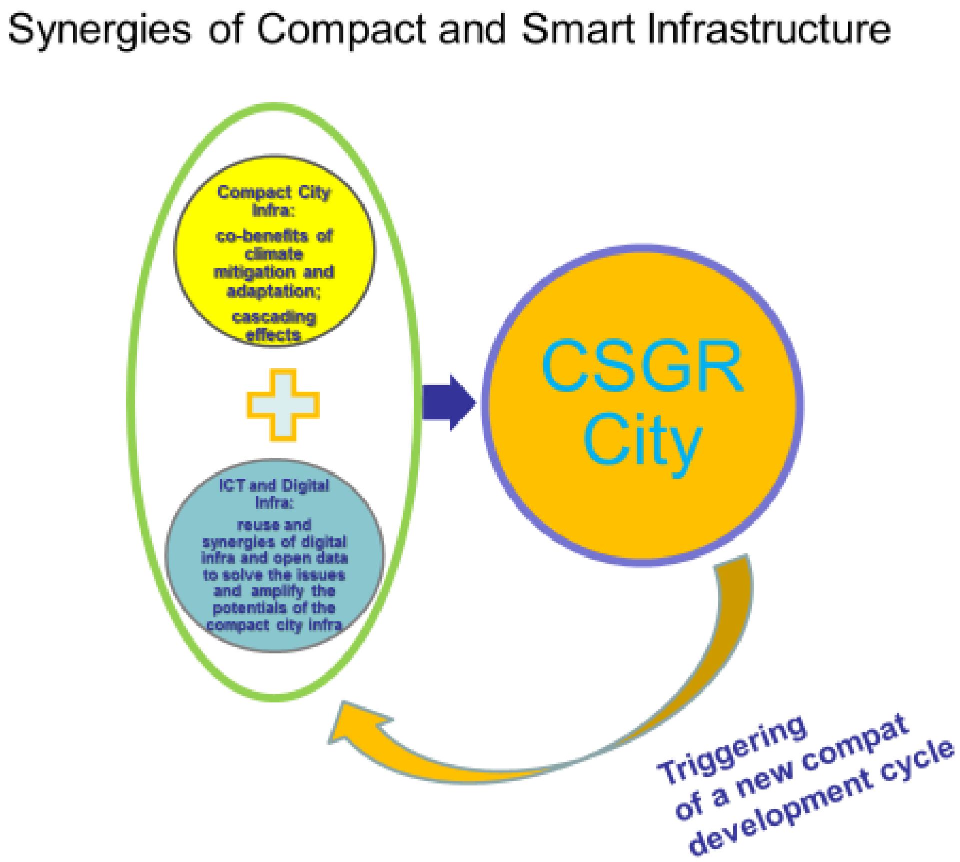

Fig. 2 Synergizing the built and ICT infrastructure to facilitate the emergence of Compact Smart and Resilient City.

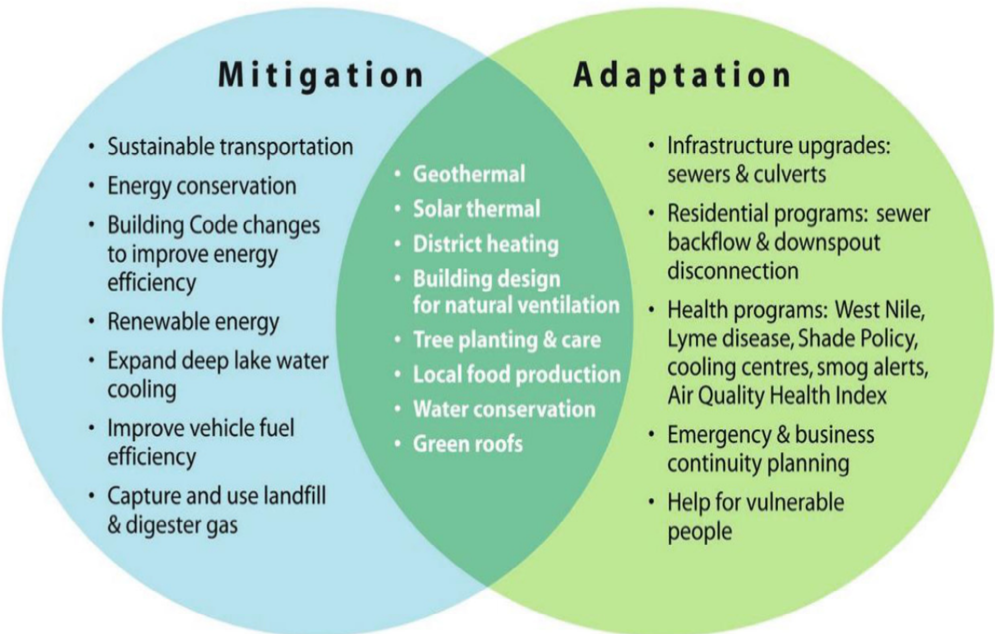

Fig. 3 Projects which deliver mitigation, adaptation and both [14].

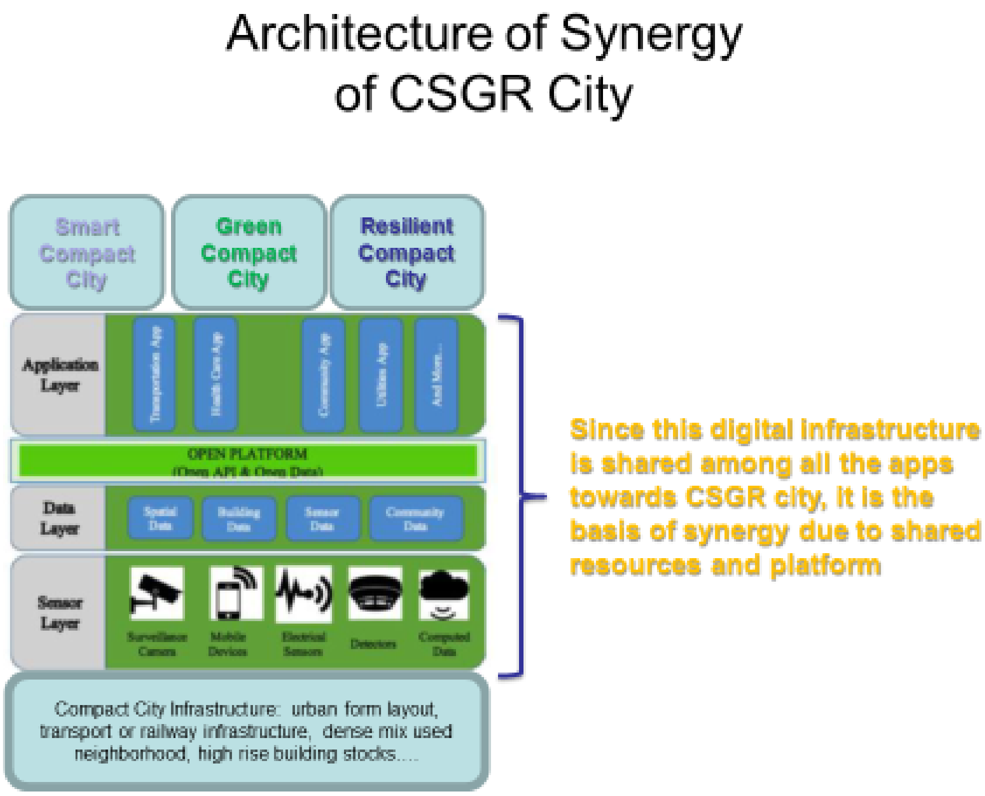

Fig. 4 The architecture of synergy of a CSGR City (adapted and modified from the advisory paper of the Smart City Consortium [13, 15]).

neighborhood more ready for stormwater of heavy rainfalls thus reducing the flood hazards. Urban farming creates a virtuous mechanism to mitigate and adapt the local climate effects and it will also improve food self-sufficiency and create jobs.

(2) [Cascading] Discrete green infrastructure needs to be joined-up to amplify their combined mitigation and adaption potentials. A concrete example is the integration of blue and green infrastructure which incorporates urban water management to irrigate the green infrastructure such as different urban afforestation programs. Another joined-up arrangement or possibility is to use the roof top spaces (which used to house the chillers and other HVAC (Heat Ventilation Air Conditioning) machinery) of buildings served by a district cooling system, now made available, for urban roof-top farming. This greatly amplifies the potentials to mitigate the urban heat island effects for high density neighborhood with canyon effects.

(3) [Infrastructure Reuse] While authors have outlined several scenarios of using digital data to optimize and enhance the operations efficiency of a given fixed built (compact) infrastructure above, a more general architecture of the interaction of the physical built and digital infrastructure could be conceptualized as reuse of the digital ICT infrastructure or platform [15, 16] across many smart, green and resilient end applications (Fig. 4) to facilitate the emergence of a CSGR City. It is important to note that this reuse is above and beyond the utilization of a given hardware technology infrastructure but also involves social learning across different applications and project developers. This social learning is especially important if such applications are perceived as tangible solutions implemented by change agents to sustainability problems. The emphasis upon use-inspired solutions and actions is a central tenet of the emerging field of Sustainability Science [17, 18]. In a more advanced

formulation, the digital [core] infrastructure and the diverse applications would co-evolve [19] thus leading to a more functional kernel to support increasing diversity of smart green resilient digital applications.

The above diverse archetypes of synergies and others could be further elucidated and conceptualized as the important ingredients of a Sustainability Science of Compact City.

(4) [Sustainability Ethics] The much simplified explanation of the two strands of sustainably at the outset could be used to inform the future development of a CSGR City. The compact paradigm operates on the premise that land mass, a critical exhaustible (excluding the reclamation of land) natural capital, needs to be conserved and a limit of how much land to use or keep must be maintained. On the other hand, for the allotted land mass for development, state of the art technology such as high-rise building, urban planning code, transportation infrastructure, etc. could be used to maximize the land development potentials. A building of 10 storeys (or a plot ratio of 10) could house the same number of households in 1/10 of the land masses compared to if these households are located in a flat land. Strictly speaking, the deployment of technology could be interpreted as substituting land masses and this is the central tenet of the weak sustainability paradigm. This convenience is not free of problems as compact development also leads to a host of negative environmental externalities which would also need technologies to solve. Viewed this way, Compact City development embraces both strong and weak sustainability paradigms, the former on the limiting of land masses consumed and the latter on the solutions to the diverse operations and implementation issues of the compact development strategy. It could be suggested that if the development density and congestion has come to a limit or maximum, new lands must be made available. This brings people back to the strong sustainability issue of the magnitude of land to use or preserve and policy makers need to go beyond just optimizing the synergies within the previous limit and trigger a new compact development cycle (Fig. 2).

6. Conclusion & Future Works

This paper motivates viewing the ongoing urbanization process via Compact City strategy from the strong vs. weak sustainability point of view. Authors elucidate the multiple roles of technology which optimizes the use of natural capitals (e.g. land mass) and mitigates the associated environmental externalities of a Compact City; specifically, technologies such as ICT could be deployed to further introduce novel urban functionalities based on the existing infrastructure.

Authors postulate that the Sustainability Science of Compact City could be formulated as addressing the various sustainability problems by leveraging several practical archetypes of synergies: those within the built infrastructure such as co-benefits of climate mitigation and adaptation and cascading (or joined-up actions of otherwise disconnected green activities) and those across the built compact infrastructure and the digital ICT infrastructure such as the reuse of a common ICT platform to develop a suite of smart green resilient solutions to optimize the operations of the built infrastructure and develop new functionalities. Future research could be directed at elucidating the specific mechanisms of such synergies and the stakeholders' organizational implications. Another potential topic is to study when such synergies become not able to tackle the problems within a full Compact City and which then warrants a new compact development cycle to be triggered [3].

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