Wojciech Kujawski, *M.Sc. Arch., MRAIC*

IMPACT OF BUILDINGS ON CONTEMPORARY URBAN INFRASTRUCTURE

Doctoral Thesis I.

Promoter:

Assoc. prof. Magdalena Jagiełło-Kowalczyk, DSc, Architect

Tadeusz Kościuszko Cracow University of Technology
Department of Architecture and Urban Planning

Kraków, July 2018

Cover photo: . Bahrain World Trade Centre. Source: iiSBE, http://www.iisbe.org/

Thesis

Buildings are subjected to the life cycle processes that have direct impacts on the built environment including the urban infrastructure.
They are implicated in the process of design, construction, and operation of the infrastructure while contributing to it by using, disposing and producing energy, water, and waste.

Table of Contents

I. PREFACE

MOTTO:

Infrastructure is what makes us able to maintain modern and functioning societies[1].

1. Introduction

The architect is responsible for the built environment that affects all the most critical aspects of human lives such as home, work, and leisure, including rest. In recent years, buildings and their related urban systems have become more complex through slow, but noticeable, integration leading to better adaptability and resilience to changing conditions, including climatic. Buildings themselves can create a sense of community enriched by the nature of a place that can be a vast agglomeration, a city, a town, or merely a collection of individual homes with socially connected, or not, people. However, buildings cannot function independently of the neighborhood if they, by their number, create an ecological environment that includes infrastructure cross-linking them together and to the world outside of their "space."

The integration of buildings and infrastructure represents a major change in urban form and building design and traditional boundaries separating buildings from their infrastructure are getting even more distorted. Distribution systems, distant treatment, and huge power plants may yield to a network of smaller distributed infrastructure systems, with elements integrated into the built environment and shared within the neighborhood.

If the technical conditions are met, it may result in the creation of the modern, functional neighborhood, community, and then, gradually, the entire city. It is like a system in the living body, but on a different scale, depending on the point of reference and much less complicated.

Cities, or urban organisms of different sizes, are neither organizations nor machines. They do not grow; they do not change, they do not multiply or repair by themselves. They are not autonomous entities, nor do they live the cycles of life, yet all of this is completed by external means, such as construction and operation including maintenance and replacements, and depend to a large extent on how these actions are directed or provided. The behavior of the infrastructure's innards can be compared to the natural behavior of ecosystems where external elements play their role, but the system itself has its requirements and rights [after Pollard, 2015].

Also, in the same way, that a single house or a human body works as a system where each component relies on all other components, (sustainable) buildings are a vital part of a (healthy) community infrastructure system. That means the system that is ecologically engineered optimizing the opportunities of a site and technology to make the built environment more sustainably integrated with the natural environment at the site, region and global scales.

Comprehensive ecosystem services planning for the built environment must be considered as

[1] Proceedings of workshop W#2011, CVUT, Prague

it is the framework where all pillars of sustainability are seen [Brown, Kellenberg, 2009]. Both sustainable buildings and sustainable urban approach create a base for ecosystem service enhancement and create alternatives for better buildings, land use, and optimized infrastructure. A need for the necessary clarification does appear: what is infrastructure?

1.1. Defining infrastructure

In this paper, the term *infrastructure* has been used mainly to describe typical technical urban infrastructure systems fulfilling one of its functions: *to transfer* - creating flow conditions for goods, energy and people; however, other definition may extend it to the human constructed systems and processes that function to generate and circulate the goods and services needed by a community.

Such definition includes buildings being supporting infrastructures, such as hospitals, schools, sports facilities, libraries, as well as technical "transferring" infrastructures, such as water, energy, transportation, waste, data, and communications systems. It also contains provisioning and regulating ecosystem service infrastructures, such as flood control, air filtration, and food production [after Mangone, 2015].

In general, infrastructure has also been defined as "***the physical components of interrelated systems providing commodities and services essential to enable, sustain, or enhance societal living conditions***" [Fulmer, 2009].

There is no intentional separation of the specific timeframe for the infrastructure by using the word "contemporary." It resulted only from the fact that the one created at the turn of the centuries and later can enter technological activities, be accurately described, dimensioned, and then controlled in its "modernity."

1.2. Aspects of infrastructure

Engineers working with infrastructure should be more cautious about society and practices than solely about the technical aspect of it.

From the 'social urban' or "soft infrastructure" perspective, the definition contains the institutions maintaining standards in a country such as economic, health, social (including people with their social networks and interactions) and cultural. Both social infrastructure components should be taken into account together with traditional practices and their mainly technical aspects, and, as in the ecosystems, where there are laws of nature, social rights in the urban environment should be respected.

Another crucial, but underestimated, aspect is the resilience defined as the capability of an urban system to recover all the functionalities and services that existed before a shock. Increasing the resilience of municipal infrastructure systems is particularly important regarding reducing the impacts of disturbances and crises, such as natural disasters and food shortages. To be resilient, infrastructure systems should be dynamic, multifunctional and modular in ways that multiple system components provide the same, similar, or backup functions [Mangone, 2015].

New infrastructure should respond to the "resiliency" that can guarantee withstanding all calamities and consideration should be given to both the experience and knowledge rather than repairs to the previous state only because it is the fastest and the least expensive way, often leading to repeated disasters within the infrastructure itself.

Each project activity aimed at improving the building's resilience to extreme events will have an impact on overall energy and water consumption and disposal, and thus on improvements in the infrastructure.

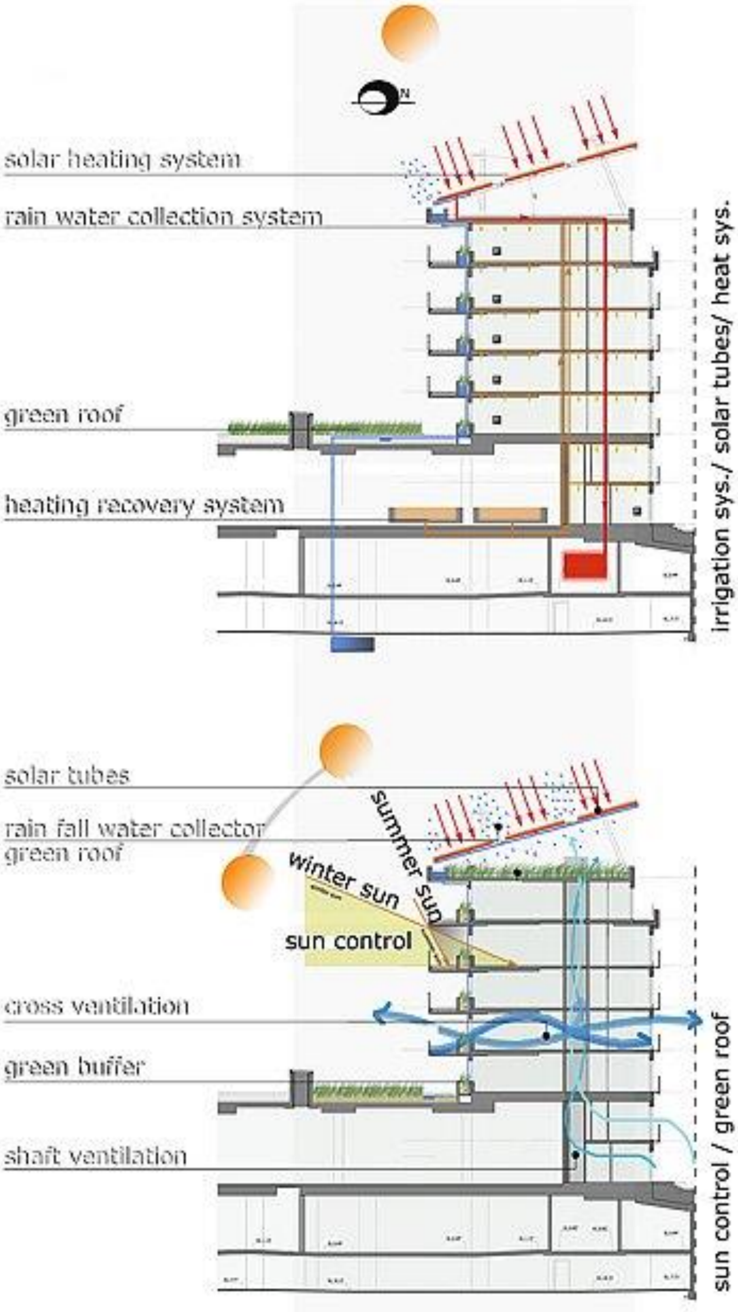


Figure 1 A simplified picture of ecosystems. Source: City of Vancouver

1.3. Building concepts

When considering the potential interactions of buildings and infrastructure as well as the optimized impacts of buildings' contribution, it is impossible to miss the entire concept of types of buildings that are to be considered to reduce the impact to municipal water, wastewater and stormwater systems. Techniques to achieve this belong to a **sustainable building**; however, if a building treated local wastewater, it would be considered part of a **regenerative building.**

Such ***buildings*** repair damaged ecosystems, replace agricultural opportunities, add to community energy and water supplies, and, in essence, become positively critical components of the community infrastructure.

Regenerative types of buildings, or groups of buildings in case of the neighborhood consideration, can have the following impacts with the emphasis on infrastructure:

- Produce enough energy on an annual basis to meet their own needs, as well as surplus energy for other buildings, freeing up capacity within local utilities and decreasing the expansion needs
- Reduce or eliminate impacts to energy, water, and road infrastructure,
- Treat water and wastewater on site,
- Provide space for local food production decreasing the need for external supplies thus indirectly GHGs
- Provide opportunities to drive less, walk, cycle or take advantage of the transit-oriented developments.
- Provide greenspaces and other community social areas [Kujawski, Pollard, Fisher, 2009].

The Integrative Design Collaborative of Arlington, Massachusetts helps builders understand the connections between buildings, the environment, and people by employing a "regenerative design" model, as shown in Fig. 2.

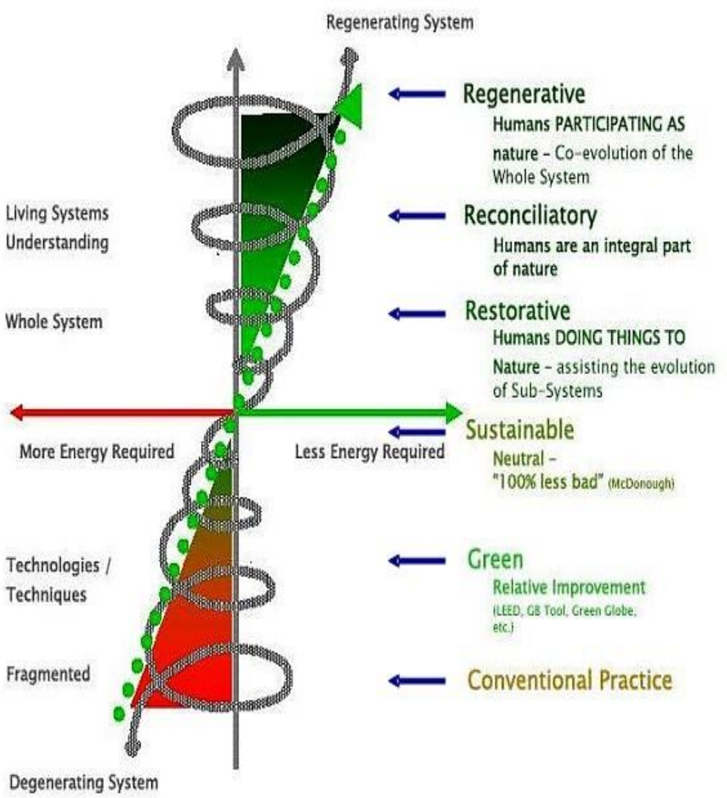


Figure 2. Regenerative design. Source: The Integrative Design Collaborative, http://integrativedesign.net/regenerative.htm

A building with a high energy demand but which produces its own heat and electricity using renewable energy sources reduces peak electrical demand, cuts GHG emissions and provides a source of reliable and secure power, might be called a real ***sustainable*** building. If that same building produces yearly an equal amount of energy that it consumes, it would be a Net Zero Energy building while with **surplus** energy that can be exported to other buildings or sold to the grid, it would be considered the ***energy positive*** building.

2. The justification for the choice of topic

The significant part of the author's professional work was related to the high-performance buildings, neighborhoods, and communities. The idea of such a correlation of the research directly related to the current thesis was born a few years earlier at the Canada Mortgage and Housing Corporation (CMHC) - the equivalent of the Ministry of Housing in other countries. The group of architects-researchers concluded that graduating in architecture does not automatically create a high level of specific knowledge about the infrastructure, besides the image of pipe networks with their never-ending construction zones, systems in and around buildings and roads with stormwater related services.

Considering a lack of sufficient information among most of the practicing architects on interrelations between buildings and infrastructure and the need for it, the group [Kujawski, Pollard, Fisher, 2009], led by the author, developed an article on such a topic for the Ontario Association of Architects and its Department of Continuing Education[2].

There are two images of the infrastructure in today's reality: the first, in a developed country, where quality and age of it are The Problems, the second, in a developing country, where quality is often not the most urgent issue, but just the lack of the systems is. As a result, one of the most critical tasks of local administration anywhere is constructing an infrastructure appropriate to the challenges of the 21st century and the way buildings are designed to be integrated with it lays down the principles behind the thesis.

When an old infrastructure breaks down, often a new one may be inadequate for any upgrade or future more extensive development due to many, sometimes unpredictable, factors. As a result, the reconstructed infrastructure will not be able to defend against any severe climate events such as, for example, hurricanes Sandy, Irma or Katrina, or similar destructive phenomena, more and more frequent and stronger.

Additionally, existing municipal infrastructure systems are currently nearing the end of their service lives, and depending on the location, are in need of substantial repairs or replacement [Mangone 2015]. The state of drinking water, wastewater, and transit infrastructure was found to be particularly negatively performing, regarding such metrics as capacity, condition, funding, future need, operation and maintenance, public safety, resilience, and innovation [American Society of Civil Engineers, 2013].

[2] The most recent article published by the author in Technical Transactions 9/17 titled " New Role of Buildings as Contributors to the Infrastructure" was the updated next step taken in similar, educational direction.
https://suw.biblos.pk.edu.pl/resourceDetailsRPK&rId=68744 (accessed May 2018)

Most infrastructure is sized for the worst-case scenario and expandability. Rarely it is expected from buildings to respond while using less. Demand-side management (DSM) is the first step that has to be integrated and acknowledged as effective allowing for the setting of new targets for sizing infrastructure and reduce costs. Linked to that concept is the decrease in demand to reduce or eliminate systems entirely within a building or any connection to centralized infrastructure network [after S. Moffat, K. Rink, 2002].

The challenge is to build a new, well-thought-out infrastructure with the best possible connections to buildings as the potential "contributors" that in general:

- share the energy produced on site and water received from the operations and rainfalls through the optimization of building design and the street themselves by the adequate urban design (refer to Module 5- "Climatic Envelopes" [DeKay, 2012]).

Both building and urban areas were researched holistically by the author in search of the best solution considering current situation.

The behavior of urban infrastructure created by buildings can be compared to the natural behaviors of ecosystems that have their strict requirements and rights. In a modified *[engineered]* ecosystem – infrastructure/ urban organism – the human creation, everything that happens physically depends on:

- type of activity (receiving or contributing)
- the degree of control
- requirements and rights for the infrastructure of buildings and their surroundings

To mitigate the size of the urban infrastructure, the significant reduction of energy demand in buildings in that urban setting is required. However, the demand decrease can also be achieved by recovering the heat losses by inefficient systems, capturing heat from sewage and by using gas emissions and municipal waste as a source of fuel. The entire urban area can be supported by increasing the capacity of the energy and water systems through the direct contribution to the infrastructure, or by the reduction of demand so that the community could be self-supporting [Fig.3] (refer to Part III).

Figure 3. Station Pointe Green, Edmonton, Canada. Mixed use development with water treatment facilitySource: Hartwig Architects

http://www.hartwigarchitecture.com/residential , accessed May 2018

Such actions can reduce direct buildings impact on the overall requirements, size including, of urban infrastructure, and can also mitigate the overall effects of climate changes in communities. Those changes can cause huge problems almost every year due to the current, almost catastrophic, situation of infrastructure in some areas being recently affected by extreme climatic, or other disastrous events, dependent on human activities or of the Earth itself. The state of potable water, wastewater, and transit infrastructure is particularly poor regarding capacity, condition, funding, future need, operation and maintenance, public safety, resilience, and innovation.

Particularly noteworthy in the coming years will be the proper planning of the fundamentals for new infrastructure, based not only on systems in buildings but also on the skillful anticipation of all possible threats such as flooding, hurricanes, heat waves or earthquakes.

For example, it is easy to refer to the massive sewage and stormwater systems that are constructed without any attempt to address the "permeability" of the surface by either increasing it or just creating a possibility for it. The consequences may become serious during and after any catastrophic event. These aspects are included in the dissertation's goals as a genesis of a question that has become more visible in recent years: ***if we single out the mechanisms and types of impact of buildings on urban infrastructure, would it be possible to improve them?***

Human beings must meet the challenges not only of nature, but also of themselves when all the limits of growth, and as a consequence, their spatial needs and the growth of virtually everything, are continuously and thoughtlessly crossed. The Earth with its limited resources is only one, and most of the humanity still cannot understand the meaning of the words "enough" or "suffice," thus the necessary connections in the dissertation of the built environment and a climate change.

To properly proceed with the thesis-related subjects, it is important to note that certain key trends have already influenced the integration of buildings with infrastructure. The most relevant are: potential massive increase in energy demand due to electric vehicles (EVs) fleet and transportation systems; increase of infrastructure cost per person due to decrease of population per dwelling unit; significant presence on the market of small and micro utility servicing equipment, including water treatment, water recycling, cogeneration and heat pumps; increase of energy storage systems that improve renewable energy potential and use of sophisticated controls to manage and optimize hybrid systems. [updated after P. Russell]

This paper focuses on the technical aspect of the built environment that comprises both the infrastructure and buildings as much as possible within the thesis that is built on sustainability principles contained in all publications and other work of the author. The topic of the infrastructure itself is, by default, also related to the so-called Green Infrastructure based on land use impacts on the natural environment. It uses a conscious approach to energy and ecological conservation in the design of the built environment. The other, indirectly relevant issues such as the elements of social infrastructure are also mentioned; however, as not directly subject related, they are not elaborated.

3. Objectives of the work

The dissertation aims to prove the thesis that it is possible to counteract unrestrained urban growth, and indirectly resulting from it climate change, in a relatively simple and logical way of using a sustainable building design as a model where the first imperative is that "**a building should be green by design instead of green by the device** " [P. Pfeiffer, a "green" architect, Austin, Texas].

Paraphrasing the thesis and converting it to the research question:

Can modern buildings, considering all their technical design aspects, but including also occupants' comfort, play an essential role in the dynamics of urban infrastructure, not only by quantitatively contributing to its performance but also constituting a conscious part of the designers' planning of new synergies between buildings and their environment?

3.1. Scientific objective:

- To demonstrate that buildings – the components of infrastructure, can be in a critical position in the new paradigm, where most of them will not only behave conventionally as "passive collectors" but that they will affect the infrastructure by co-creating, as contributors, new synergies with the built environment.

3.2. Educational objective:

2. To present the facts helping understanding limitation of continuous growth of the infrastructure due to population needs and continuous climate variations, primarily through well-thought-out design, and then by the use of technologies, but only when and where justified by needs, either technical, social or economic, whichever aspect is contextually most relevant.
3. To combine in the final synthesis the interim conclusions of the ideas developed by others such as community-level synergies with urban patterns that fit perfectly into the concept of the thesis using it while benefitting from other pertinent research.

Application objective:

- To demonstrate, in support of the thesis, practical ways for the conventional building to be better integrated with infrastructure and show what changes have to be made to the design process to achieve effective integration that can be beneficial for buildings, infrastructure, and the planet.

The "side objective": to see and understand the different dimensions and to generate an idea of the holistic approach to the issues of the built environment, so that the mutual relations between the details and Planet Earth are visible [Fig.4].

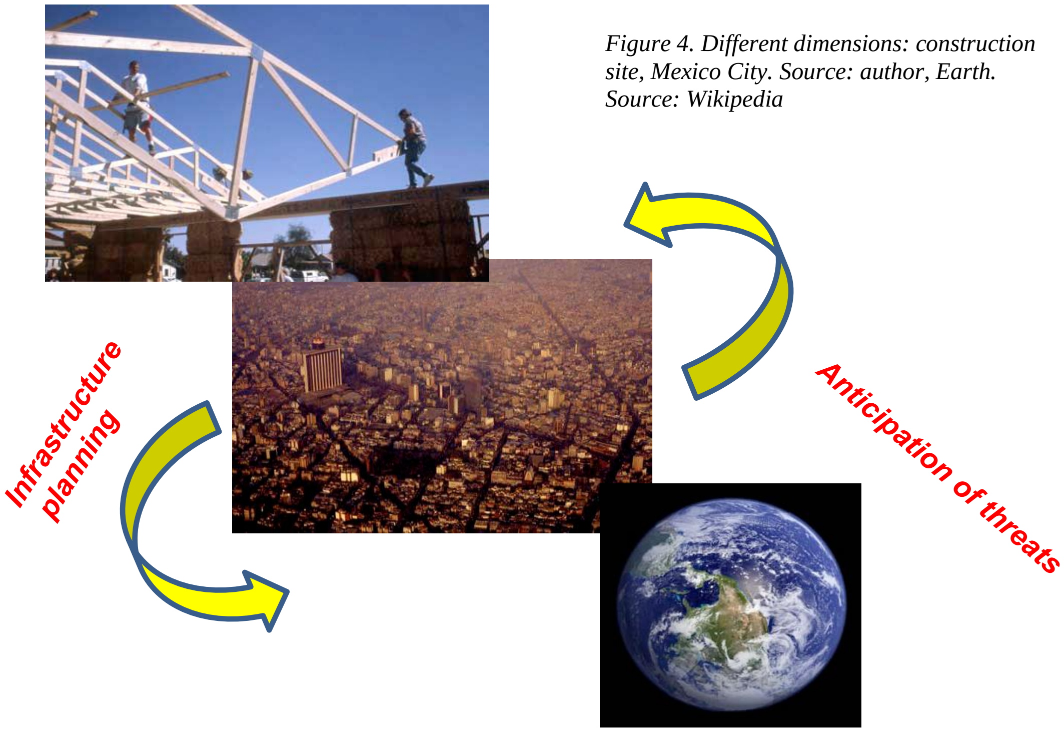


Figure 4. Different dimensions: construction site, Mexico City. Source: author, Earth. Source: Wikipedia

All those objectives encompass not only sustainability in construction, but also author's professional work in other sectors of the economy related to construction, such as transportation, and his interest in its derivatives like urban design patterns, that impact on urban infrastructure performance when measured by the Green House Gases (GHGs) outputs and other sustainability indicators.

4. Subject of work

Given the justification for the topic and the objectives, the main subject is the analytical presentation of research on the mechanisms and types of impact of buildings on urban infrastructure combined with redefined neighborhood scale synergies. The possibility of such endeavor came from the overall professional experience of the author who has been working with the issues of energy and built environment[3] for over 25 years of almost 40 years of his overall professional activities.

5. Scope of work

5.1. Territorial scope

Most of the research is related to Canada; however, as the country extends through several

[3] Author's involvement started in Canada in 1992 with the process of adaptation of the Canadian R-2000 highly (then) advanced housing Program for Polish Ministry of Housing and the Energy Conservation Foundation in Warsaw run by late A.Panek. The author created and ran the official governmental Fact-Finding Mission to Poland. In 1993 he developed the C-2000 Program Requirements Manual for Natural Resources Canada that was followed by further significant work such as a development of the Building Assessment software called GBTool[3]. That work was followed by 12 years of participation in the Canadian National Team as an active member assessing several buildings including Angus Technopole in Montreal, Red River College in Winnipeg, University Learning Center in Kingston and the South East False Creek Olimpic Village NetZero building in Vancouver. He also worked with national teams in USA, Japan, Germany, and Poland helping assessing several GBC /SBC buildings.

climatic zones, the overall conclusions, as well as used methodologies can be smoothly interpolated to almost any location. The examples supporting the improvements to the potential direct and indirect contribution to the infrastructure are shown in all relevant modules. The examples of the built environment are from different regions and countries – from selected cities in North America, Europe to Asia. They illustrate concepts for mainly residential buildings in their different development forms, including single housing in an urban context, as well as issues related to development, design, and construction of sustainable buildings and communities.

5.2. Time range

The time span is limited to the formative years of modern infrastructure - the late 20th and early 21st centuries - the most significant period for improvements considering presented studies.

6. Methodology

The main topics introduced by the author and contained in modules broadening and expanding the thesis are related to most aspects of the infrastructure relevant to the buildings that can be designed, and built in a specific way while their operations can also be optimized. The building relationships with infrastructure systems (electricity, heating and cooling, waste, water, communication) go in two directions: the co-creation/contribution side and the collection side. They are both dependent on building and community development plans, where the expansion of a required infrastructure or its reduction in size, may be planned and those subjects constitute the base of the dissertation.

6.1. Structure of work

The dissertation is based on two volumes: Doctoral Thesis I as the primary document and Doctoral Thesis II containing five modules with supporting materials.[Fig.5].

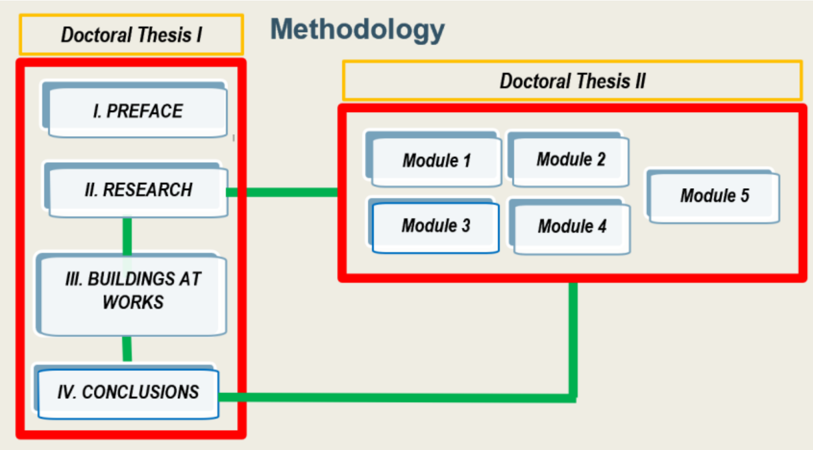


Figure 5. Methodology. Source: Author's own study

Modules are structured with topics related to the buildings, urban environment and infrastructure, and their mutual dependencies in the operational phase of the life cycle [Fig.5a]. The work itself does not have the elements of standard research because it consists of studies that have already been completed. The summaries from five modules present research on buildings contribution to the infrastructure.

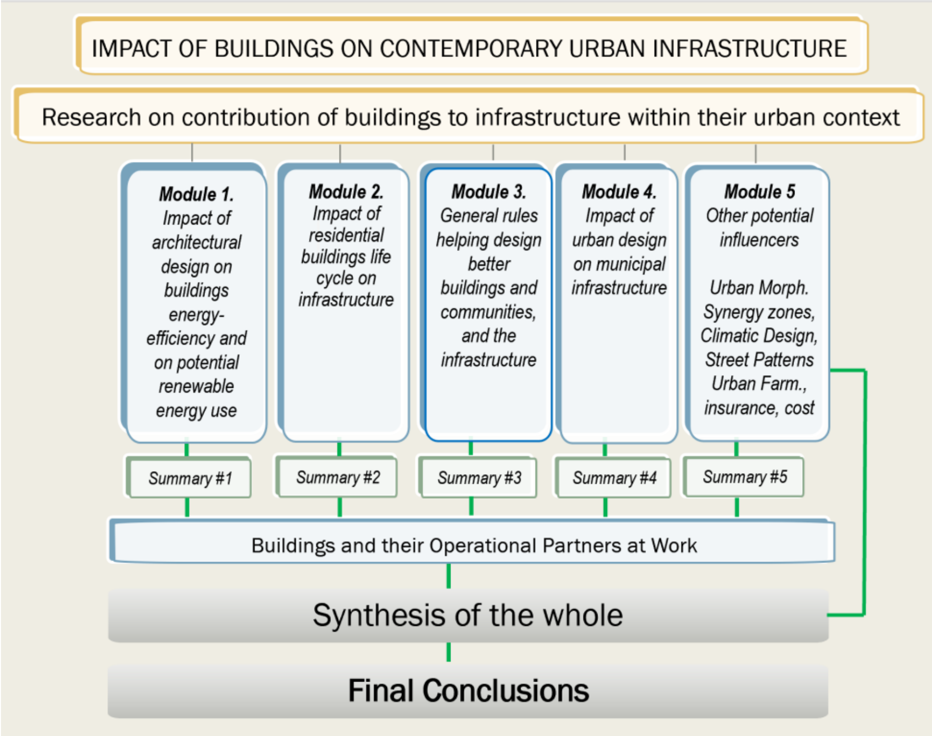


Figure 5a. The synthesis method. Source: author's own study

The modules in Doctoral Thesis II are introduced to facilitate the overview; however, their summaries are integrated into the primary document (Doctoral Thesis I) presenting different aspects of research related to the thesis.

The first four topics are addressed by broadening the scope of the response with the help of multiple studies that were invented or created, proposed, authored or co-authored, and managed by the author.

They support the thesis directly or indirectly in addition to their relation to the particular research topic itself. In each module, the conclusions from research publication (or group pf publications) are presented at its end, and then all conclusions are treated collectively in the Summary of the Module as one of the elements to prove the thesis in the Synthesis of the Whole before reaching the Final Conclusions [Fig.5b].

The fifth module contains the works of other authors that are spread over the main descriptive parts of the dissertation and especially in the section called "Buildings and Operational Partners at Work" where the primary case studies are presented together with recently updated aspects of infrastructure introducing the new, more holistic, approach to it.

The main such aspects are the following: the Synergy Zones [Larsson, 2011], the hybrid infrastructure [Mangone, 2015] and the Fused Grid [Grammenos, 2008-12]. They are all combined with the conclusions from Sustainable Communities [CMHC, 2009] and Climatic Urban Design [DeKay, 2012] with the awareness of the use of Big Data to create the adequate results. In addition to the use of research and professional experience in support of the thesis as the primary purpose of the citations, other aspects of the design linked to the infrastructure, are also addressed. The clarifications consider the fact that they stand as the extensions or conclusions of the published article, which already has its analytical elements developed with other referenced authors or solely by them.

The nature of research is to explore existing resources - in the case of this work mainly the author's publications - and use them in the subsequent studies. The already conducted research and the presented thematic studies by others allow for the observation of different proposals and behavioral patterns of buildings that co-create and impact an urban infrastructure where and when certain conditions are met.

The borders between modules are not very rigid and, in many instances, it was necessary to extend or borrow, part of the research, to another place in the dissertation. It may then overlap with results in other modules, especially the ones with connections to both building and urban issues. Some research elements are exclusive to the study area like for example a "building energy." However, if the objective of another study is different, but it also uses the "energy" component, then it is used in both or more, places while being related in an urban study to the total neighborhood energy and in building performance to the same in micro scale.

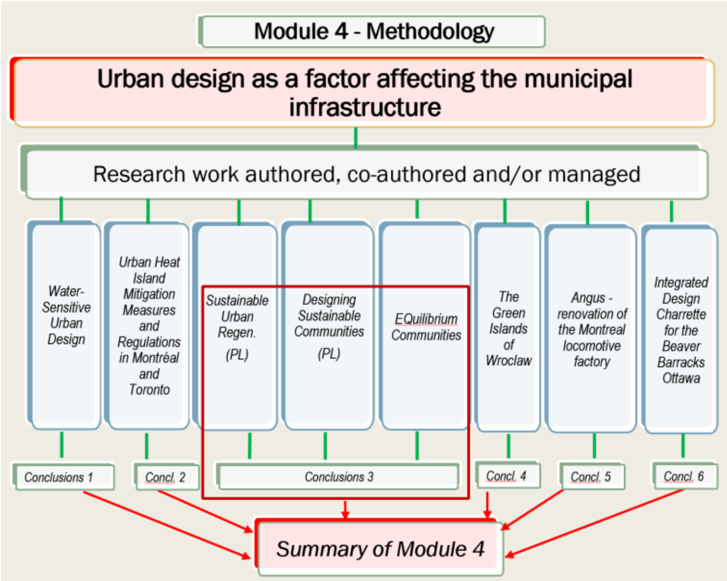


Figure 5b. Methodology on the example of Module 4. Source: author's own study

All elements of the author's coherent approach to the issue of sustainable design and his ties to urban planning in the context of impact on the infrastructure are taken into consideration, and the results from his direct experience as the designer or co-designer of buildings and neighborhoods or communities on several continents are also provided.

In the end, the thesis relevant work of the author, in both research and professional practice, is completed in the synthesis and summarized in the final conclusions.

7. The state of research

7.1. Existing research background

The author uses already completed studies (his own and by others) that permit him to combine the requirements or predicted performance with the actual case studies or conditions of buildings co-creating infrastructure. The conclusions drawn from the entire work of the author, both research and practical, serve to prove the thesis.

7.2. General notes on the conducted research and related activities

It is important to underline that the research presented in the modules was heavily edited by the author depending on the level of relevancy to the criteria contained in the expanded thesis. In multiple cases, the additional comments were made to emphasize either the relations to the infrastructure or other current and updated aspects of the presented research. The removal of the thesis's unnecessary parts of the research may potentially create an impression of the incompleted studies; however, the references or links to full texts are provided.

Often the problems revealed in this dissertation are unnoticeable or are treated marginally, whereas in the "real" world they can play a significant role. An urban heat island could be a good example - only during the memorable "heat wave" in 2003, they formed hot enclaves, indirectly contributing to the death of 14,000 older inhabitants of French cities.

The infrastructure situation can be improved by monitoring the operation of all systems, and the author's research was carried out with real projects in Ottawa and Montreal, Canada. The goal, in that case, was to ensure that the assessment of the effectiveness of major projects can and should take into account not only building performance itself but also the effects of future possible climatic changes, which may affect the safety or operations of buildings and areas surrounding them.

The author’s years of monitoring or supervision of the processes in the high-performance buildings and communities in Canada can guarantee that the presented results are reliable, and the conclusions of each research work are accurate. However, due to the constant technological advances in the built environment and impossibility of following all changes and upgrades, some may not be sufficiently, or not at all, updated to the present state of knowledge and technology.

The mere fact of monitoring the efficiency of systems within urban areas provides building operators and local communities with a constant supply of information on energy and water efficiency and other local systems such as, for example, earth heat pumps if used.

II. RESEARCH

Research Overview

Research on the mechanisms, types of impact and potential improvements to the contribution of buildings to the urban infrastructure in direct support for the thesis is mostly provided by the author's coherent approach to the issues of interdependencies between sustainable building design and its urban context. Topics were chosen with criteria reflecting influences of both aspects on each other.

1. Criteria for the selection of research topics

Simplified research thesis: **Buildings can play a significant and positive role in co-creating contemporary urban infrastructure.**

To conclusively demonstrate and prove this thesis with materials based almost uniquely on author's work within the relevant area of expertise, it was necessary to devise a simple formula that would allow for subject-based publications to be presented while creating clear conclusions related to each level of the analysis. However, the summaries of each module serve only as a source for the final conclusions as they are interrelated due to the overlapping subjects within the sustainability.

To achieve the above goals an idea of several main topics related to author's research and other professional work was created with the following criteria: sustainable buildings and communities, energy efficiency, high performance buildings, renewable energy, innovation, infrastructure, green buildings, urban design, ecological design, passive house, community energy, solar energy, environmental policy.

It was apparent that too many topics could create some confusion and the final list was formed after the consolidation of them on the higher, more inclusive, levels. The publications on building design and its impact on infrastructure but in the form of research on features in specific buildings and neighborhoods were grouped in **Module 1** „***Impact of architectural design on buildings energy-efficiency and potential renewable energy use*.”** Some of the research was also based on extrapolations of actual results and ideas of more general approach to those subjects.

The same principle of specific research but on urban matters impacting on infrastructure developments was used in the creation of **Module 4 - “*Impact of urban design on municipal infrastructure”.*** The purpose was to gather the type of information that could help visualize the locations and their contexts with already implemented right (or wrong) principles of urban design on a scale of a neighborhood or a community.

Two modules mentioned above have their borderline almost invisible as in reality an urban design consists of buildings- they are always there and are built within specific urban concepts (a”concept” means any given location and its context which may not be necessary a result of any deep “urban thought“). Both modules share the contributors –buildings, which are constructed within urban planning idea, or not. However, the distinction between two topics was necessary to keep two issues separate as much as possible, even if the infrastructure depends on both.

Another reason for such a decision was in the creation of **Module 3 - „*General rules helping design better buildings and communities and the infrastructure”*** where the research and other publications are located (including the reviews of procedures). They contain general design measures applicable to buildings and their urban context but in forms of guidelines for designers and researchers. Some areas of the conducted research may overlap parts of other modules, but often it was inevitable. However, it was beneficial for the thesis.

The topic of Module **2 – *„Impact of residential buildings life cycle on infrastructure”*** takes care of the conducted research on several subjects. Some are related to the environmental impact of housing from the typical single detached homes to the housing issue on a scale of a country. Their impacts on the infrastructure with its resilience in all forms are shown from adjustments to ever growing residential construction with infrastructure requirements, to catastrophic events requiring the same.

All the work presented in topics mentioned above ends up with conclusions summarized at the end of each topic (shown as ***Conclusions*** **# x**, referring to a number shown on a graph of a topic's Methodology) with some combined within similar subjects; however, there was still a need to introduce other work that could complement the research presented by the author.

Thus, the **Module 5 -" *Other potential influencers”*** was developed with the ideas known to the author through either the joint work with those researchers, but on other matters, or from references; the relevant work researched and developed by others is invaluable in the overall aspect of the support for the thesis.

The author managed referred research work either as a sole or main contributor or as in most cases, a CMHC's Project Manager directing the research work of listed consultants often during several consecutive years. Most of the published studies have the internet locations provided in their respective modules.

2. Overview of the infrastructure types

To assess the appropriateness of the module's topics as the basis for further study, the Table.2 below provides the overview of the infrastructure's types that buildings can contribute to and their relations to modules-appendices.

Table 2. Types of infrastructure buildings can support

Infrastructure Component	Sustainable Building Element[s]	Potential Benefits to the developer, occupants, municipality, and/or the community
Energy [heating, cooling, electricity, ventilation, humidification] ***Module 1, Module 2 Module 3***	▸ District heating [renewable or fossil fuels] ▸ Renewable energy [wind, micro-hydro, solar thermal, PV, geothermal] ▸ High-performance building envelope ▸ Use of thermal mass [passive solar design] ▸ Natural light [solar, light tubes] ▸ Energy-efficient lighting ▸ Controls [sensors, timers] ▸Natural, no- or low-VOC finishes [related to indoor air quality]	▸ Reduced energy demands on municipal or provincial utilities ▸ Reduced equipment sizing requirements ▸ Improved indoor and outdoor air quality ▸ Reduced GHG emissions through energy efficiency and reduction of fossil fuel use ▸ Reduced operating and maintenance costs for owners and occupants ▸ The growth of renewable energy and sustainable building technology sectors ▸ Revenue opportunities to sell surplus energy or carbon credits
Roads & Transportation ***Module 3, Module 4***	▸ Optimal street design [e.g., fused grid] ▸ Transit-oriented development ▸ Limited parking spaces ▸ Active transportation infrastructure, [bike paths, racks, and storage, sidewalks,]	▸ Reduced urban heat island effect ▸ Reduced GHG emissions and improvement of air quality with fewer cars on roads ▸ Reduced costs to developers with fewer parking spaces and freed up land
Water/ Wastewater/ Storm water ***Module 2 Module 3 Module 4***	▸ Permeable surfaces ▸ On-site water reuse ▸ Stormwater management techniques ▸ Green roofs ▸ Rain capture systems ▸Water efficient appliances [low-flow fixtures]	▸ Reduced impacts, size and cost to municipal water, wastewater and stormwater systems ▸ Reduced stormwater runoff ▸ Reduced water costs for occupants ▸ Reduced cooling requirements and the urban heat island effect with green roofs
Waste (garbage, recycling, composting) ***Module 2 Module 3***	▸ On-site composting and/or recycling facilities ▸ Reusable/recycled/recyclable building materials ▸ On-site waste reduction during construction and demolition	▸ Extended lifespan of municipal landfill sites ▸ Reduced GHG emissions from landfills [methane = 20x the global warming of CO_2] ▸ Reduced landfill tipping costs by limiting waste during construction and creating revenue from selling useable construction materials
Any of the above ***Module 5***	Any of the above	Any of the above

3. Research Topics

3.1. Impact of architectural design on buildings energy efficiency and potential renewable energy use, *Module 1*

3.1.1. Introduction and Content

This first Module is the essential component of the dissertation being directly related to all aspects of the buildings themselves either being newly designed or retrofitted, thus responsible for the requirements of infrastructure for and around them. The idea was to approach the building from the design point of view and present, through the research findings, the design considerations, and results of the implementation of architectural features that can affect the municipal infrastructure.

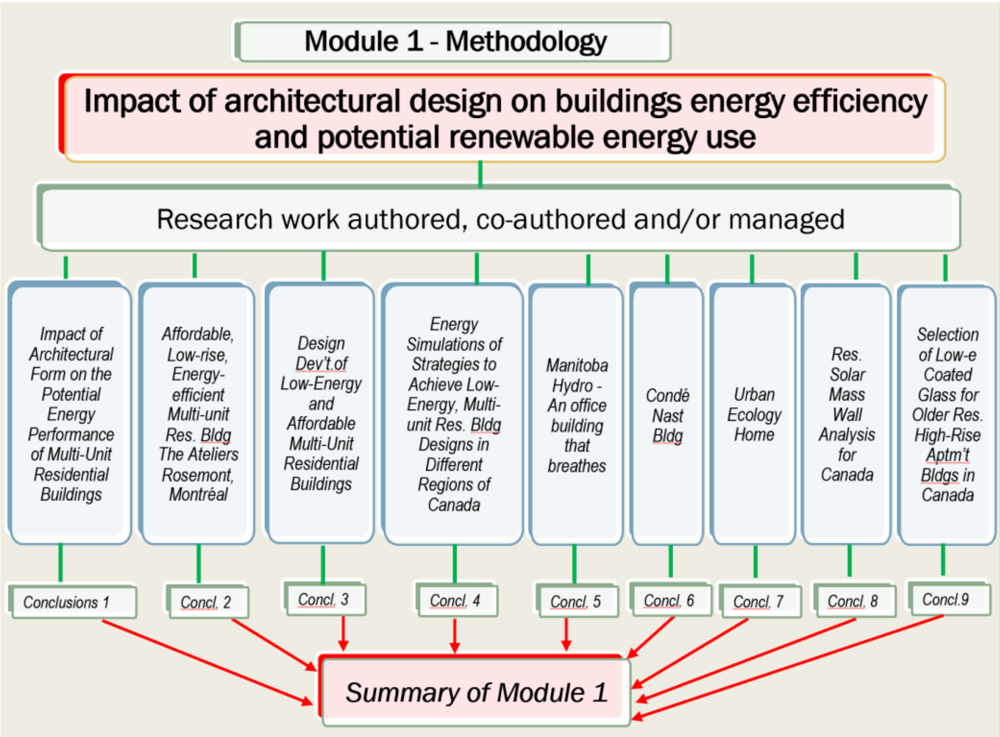


Figure 6. Methodology of Module 1. Source: author's own study

The presented research encompasses all significant aspects of the building design starting with the location and orientation and the concept of the form and other architectural features (***Conclusions 1*** p.10***)***. Then the ideas of glazing, thermal massing, bridging are all taken into very sophisticated energy simulations. (***Conclusions 2*** p.15***, and Conclusions 3*** p.18). The results are taken further to real design and then back to the universal aspect of the question how to build the best performing buildings across the country as vast as Canada with its several climatic zones (***Conclusions 4*** p.23***).*** Several best buildings in North America are assessed from the point of view of efficiency in all aspects of their design and later in operations (***Conclusions 5*** p.28***, Conclusions 6*** p.31***, and Conclusions 7*** p.33***)***. Some additional studies on particular aspects of glazing and thermal massing were also conducted (***Conclusions 8*** p.35***, and Conclusions 9*** p.37***).*** The main point is that the more efficient building is, the better is its contribution to the size and general capacity of the infrastructure. Conclusions indicated above contain points that may not be included in the summaries.

3.1.2. Summary of Module 1

Presented and analyzed buildings constitute models for optimizing almost every aspect of the design that impacts on the infrastructure in its urban, or suburban environments. Buildings that use less energy overall reduce their dependence on fossil fuels and cut GHG emissions that contribute to smog, air pollution and on a global scale, climate change. Such reductions have direct or indirect impacts on municipal infrastructure which, with its usual deficits, offers opportunities to buildings to lessen their impact on or add to the capacity of its systems if only architects and engineers apply the appropriate design practices complementing them with appropriate technologies.

The critical aspects of buildings that can have an impact on infrastructure:

Net-positive energy buildings designed to produce more energy than they consume can free up capacity within established energy systems and provide safe, secure and reliable sources of energy. Buildings that include all water treatment systems and also manage stormwater can reduce the impact on, or eliminate the need to be connected to municipal water systems. The buildings built to the best standards will minimize the expansion of infrastructure to the minimum required and every step towards the efficiency of buildings contributes to the optimization of the infrastructure as well.

Most significant recommended measures for MURBs and commercial buildings through the corroboration of research for both:

The studies for MURBs and commercial buildings show that several architectural form parameters can significantly impact the annual heating and cooling load intensities [Module 1 p.9,10]. The most critical factor, relatively independent of the building geometry, was the combined building envelope performance considering wall insulation value, window U-value and window solar heat gain coefficient (SHGC), and the window-to-wall ratio (WWR). Floor plate geometry and building orientation typically have minor impacts on heating loads and slightly more significant impacts on cooling loads (being always within close range of one another). Good envelope performance is essential, and it allows freedom in massing/orientation and the building geometry.

One of the developed tactics is the use of a significant amount of insulation, minimized losses through the window frames (with location and orientation relevant glazing), use of thermal breaks, and the application of necessary airtightness. However, the amount of embodied energy in massive amounts of certain types of insulation and the impact of materials would bypass most of the energy savings from the increased performance.

By following the rules of an energy efficient design, the use of technologies can be either significantly mitigated or avoided entirely. Almost all roofs, being part of the envelope, can mitigate rainwater impact and heat losses and gains, can affect air quality, potential food production as well as the installation of solar collection/energy production systems.

As shown in the examples, net zero and net positive buildings and neighborhoods are becoming more and more commonplace—either as new construction or retrofits of existing buildings and building developments/ neighborhoods. Relatively easy construction of Net Zero Ready buildings that are resilient and with little or no special maintenance itself will have a huge impact, if built in numbers, on every aspect of the surrounding infrastructure including energy, potable, grey and black water, stormwater and waste.

In determining the environmental impact of the buildings, it is essential to take into account the perspective of the buildings' life cycle through the approach called Life Cycle Assessment (LCA). It depends on used materials, the impact of the design itself, construction process, operation and maintenance during the period of use and the demolition. Such an assessment can provide useful insights into both the durability[4] and resilience[5] of all relevant elements. The development of both the building and the infrastructure is influenced by the balance of benefits and losses and require a detailed study with all considered conditions.

The use of the low impact materials can significantly reduce the environmental burden of buildings. Durable materials and the buildings constructed with them can provide a better outcome and allow optimization of the resources required to maintain and repair buildings such as energy with its emissions, waste, and transportation therefore directly impacting the size and quality of the infrastructure.

The results from the study on Net Zero Energy home designs indicated that they were considerably more materially, technologically and hence energy-intensive if compared to the conventional building code requirements or more advanced Canadian R-2000[6] design baselines. However, the operating energy demand of the NetZero designs was found to be between three to five times lower than their comparable versions. The results also demonstrate that the energy embodied in the projects targeting net-zero energy consumption or better makes up a much more significant proportion of the overall life-cycle energy.

Designs and construction practices allowing for long useful lifetimes represent efficiency in resource use. The principle belongs to both the buildings and the infrastructure interchangeably affecting the direct energy consumption and the embodied energy related to the used materials in cradle-to-gate (extraction to operation) principle. It is necessary to understand better the implications of material choices to ensure that operating energy objectives do not come at the expense of increased embodied energy use and environmental impacts.

Design of more durable building reduces the exposure of the building envelope to moisture, the primary building deterioration factor, through improved drainage around foundation walls, improved

---

[4] the selection and integration of durable, low- maintenance building elements, equipment and systems that greatly reduce potential future risks, in the short and long term.

[5] future adaptability or "future proofing"—the selection of resilient building systems that can be adapted over the long term with changing demands on thebuilding including changes in energy sources, climate change and severe weather events.

[6] R-2000 is a voluntary standard developed by Natural Resources Canada (NRCan) in collaboration with Canada's residential construction industry.
R-2000 promotes the use of affordable, energy-efficient building practices and techniques, clean air features and other measures to help protect the environment. Certified R-2000 homes are on average 50 percent more energy-efficient than typical new homes. (source: https://www.nrcan.gc.ca/energy/efficiency/homes/20564 - accessed in May, 2018

air tightness of the envelope and better weather protection of the facade. Use of slightly more, or of a higher quality, materials can significantly improve the durability of the building or its infrastructure. Designs must also take into account ease of maintenance and repair of the critical components in the building and should be forgiving — ensuring that a failure of any component of the building does not cause long-lasting, irrevocable damage. The typical financial problem is that shorter payback periods valuing ’the quicker, the better’ (not necessarily, the cheaper) usually disregards what the best for occupants and the environment is.

The research findings illustrate the benefits and trade-offs associated with the pursuit of high-performance design, namely, low operating energy consumption versus increased material usage and higher related embodied energy. The study shows that residential energy efficiency measures and renewable energy generation systems are effective means to lower overall life-cycle energy use and many environmental impacts—though not all.

The presented characteristics support the thesis: the use of specific materials in buildings, even if environmentally wrong, can contribute to the decrease of the energy consumption and, as proven, is a leading factor contributing to the size of the required infrastructure in both utilities and transportation services area.

However, it is imperative to look at all aspects of such a contribution. High performance and resilient buildings and by default types of the neighborhood (always related to buildings) with their equally resilient infrastructure may stay in shape against the adverse weather or other events but can also contribute very quickly to the damage of the environment, and that is where and when the balance must be found.

3.2. Impact of residential buildings' life cycle on infrastructure *Module 2.*

3.2.1. Introduction and Content

Raw materials can involve high energy consumption - embodied energy in the building production stage that also determines future energy consumption to fulfill all operational demands. In determining the environmental impact of the buildings, it is essential to take into account the perspective of buildings' life cycle, depending on used materials, the impact of the design itself, construction process, operation and maintenance during the period of use and the demolition.

The Life Cycle Analysis (LCA) is used to support the thesis in regards to the way we construct the buildings and neighborhoods with interconnecting infrastructure systems that create the built environment. The undertaken studies concerning the quality and conditions are combined in this module with other aspects that determine the extent of occupants' satisfaction and also measure the overall building performance. That gathers, together with monitoring, the data ready for further analysis and actions, if needed, such as thorough energy and environmental assessment of a given design in its several phases from concept to operations. The thorough understanding of the functioning of a building can directly link its actual performance to either innovation or corrections. All those measures affect the infrastructure directly.

Module 2 contains a detailed environmental assessment of the most progressive Net Zero Energy homes (***Conclusions 1*** p.10***)*** followed by the comprehensive study of the long-term environmental impacts of housing (***Conclusions 2*** p.17***).*** Other studies analyze the level of comfort and satisfaction through the detailed surveys and protocols providing necessary steps for evaluating the operations of buildings with Post Occupancy Evaluation manual (***Conclusions 3*** p.22***).*** As materials and technologies play a crucial role in the actual performance of any building, they are also crucial in impacting on the infrastructure and also in creating it (***Conclusions 4*** p.27***).*** The overall impact is measured by the research-oriented assessment tool developed by the author and called at first GBTool (***Conclusions 5*** p.34***).***

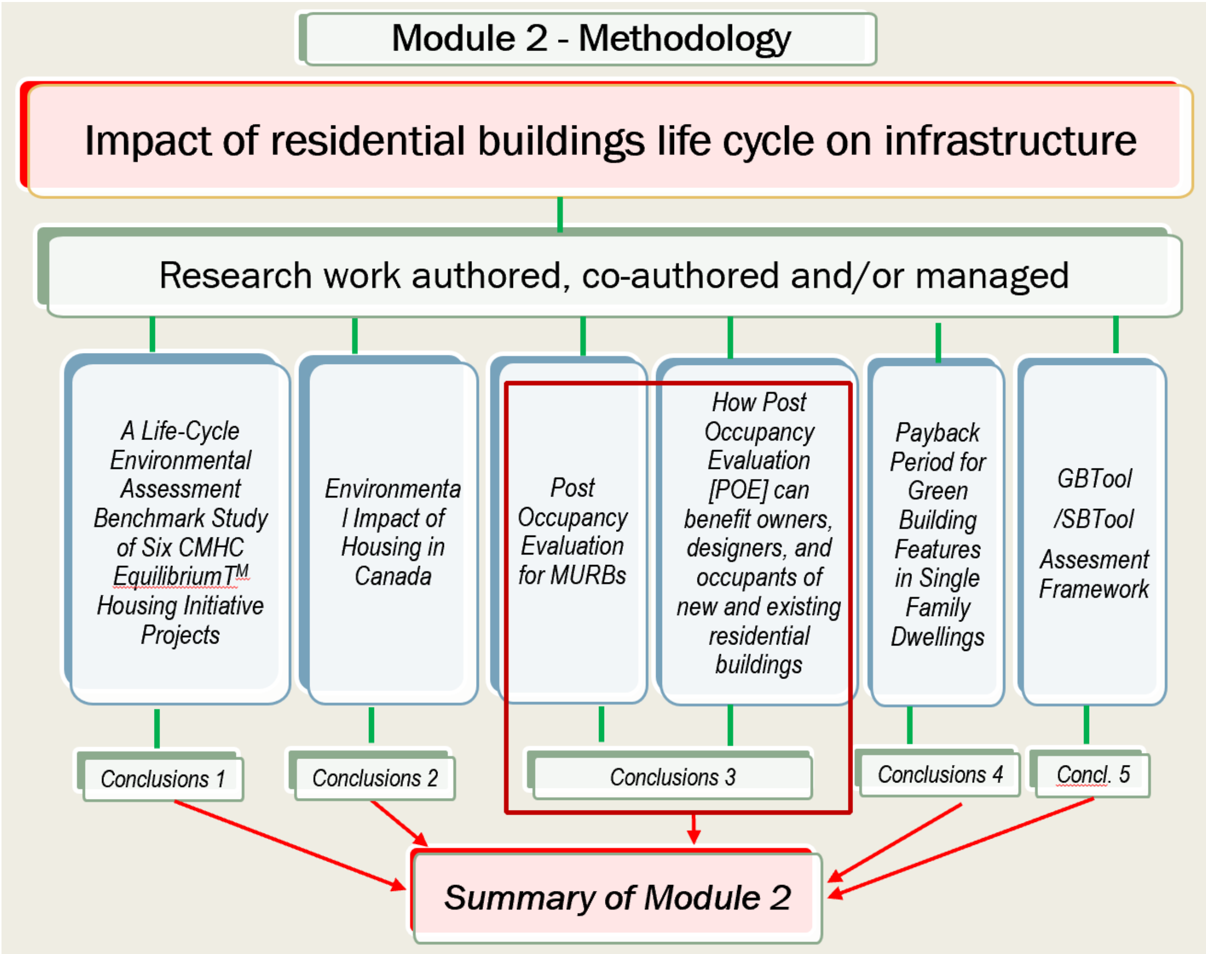


Figure 7. The methodology of Module 2. Source: author's own study

3.2.2. Summary of Module 2

Land use patterns can be characterized in terms of amount, density, mix and location of housing, and these elements, directly and indirectly, affect infrastructure requirements, transportation mode choice and the building stock which, in turn, impacts energy and other resource use. Regardless of dwelling type, neighborhood type contributes to the transportation pattern of residents thus to road infrastructure. When considering dwelling types, single detached houses would have the highest environmental impacts, and among neighborhood types, outer suburbs would have the highest environmental outputs per dwelling.

Those impacts will be mirrored infrastructure wise thus the consideration should be given to these aspects areas of housing developments. Despite the decrease in water consumption, total water use will still increase due to the growth of the entire residential sector. The water usage has major dimensions: the supply and the depletion of the water resource and the effects on water quality, partially addressed by urban water treatment infrastructure.

The operating life-cycle stage (direct and indirect) has a much more significant environmental impact than other life-cycle stages; the reductions in these impacts are limited unless existing dwelling stock is addressed with such life-cycle energy influential factors as neighborhood and dwelling choices, dwelling condition, and occupants behavior.

The initial Post Occupancy Evaluation (POE) survey determines the extent of occupants' satisfaction and monitoring of equipment and systems gather the data through all seasons, preparing for further analysis and actions if needed. Thorough understanding of the building's functions can directly link its actual performance to either innovation or corrections. All those measures affect the infrastructure. The findings from POEs can improve the operation of existing buildings, and the design, construction, and operation of new ones. Such improvements will have an impact on the level of the infrastructure use – existing and planned. Relations to the infrastructure while evaluating building performance are apparent, and the POE is an excellent opportunity to improve it.

The engagement of the residents in operation and maintenance of their building may also play a key role in the overall energy use and savings. An additional aspect is reserved to human factors such as level of occupant's satisfaction which if positive, limits lost energy in vacancies and unused urban spaces contributing indirectly to the more stable infrastructure loads.

Occupants, with their behavior impacting the building performance, create a valuable contribution to the infrastructure underlining the fact that they determine the outcome of most energy efficiency measures. The use of data representing internal rates of return -IRRs and simple paybacks in materials and technologies shows the need for precise economic analysis and performance modeling in estimating these values, as well as the importance of factors such as house type, location, fuel type, levels of insulation and air change rates. Without this approach, the consumer can be easily misled by simplistic statements.

The author developed the first version of GBTool, a building assessment software, under the guidance of the International Framework Committee (IFC) representing 14 countries. Whereas other main systems (BREEAM, LEED) remain primarily applicable to conditions in the country of origin, the GBC framework - the GBTool software (currently SBTool) is designed to allow easy identification of local factors and the insertion of region-specific values for benchmarks, weightings and standards adding to an assessments a possibility of seeing immediately the implications of measures considered in a design.

The implications of such sets of data or statements being received every day are huge in today's global economy where decisions are based very often on a so-called Big Data with the proper, regulatory verification still not existing. The reliable performance claims an anything green must be supported by reliable analytical processes helping, in the end, making the right choices.

3.3. General rules helping design better buildings, communities and the infrastructure – *Module 3.*

3.3.1 Introduction and Content

Module 3 encompasses the research, reviews of procedures and other publications in forms of guidelines about general design measures applicable to buildings and their urban context.

It is essential for the building and its neighborhood to function correctly and be built following the principles established for the sustainable built environment. Several guidelines created or managed by the author establish the design process and further procedures to create buildings and infrastructure in a new way of supporting and benefitting each other.

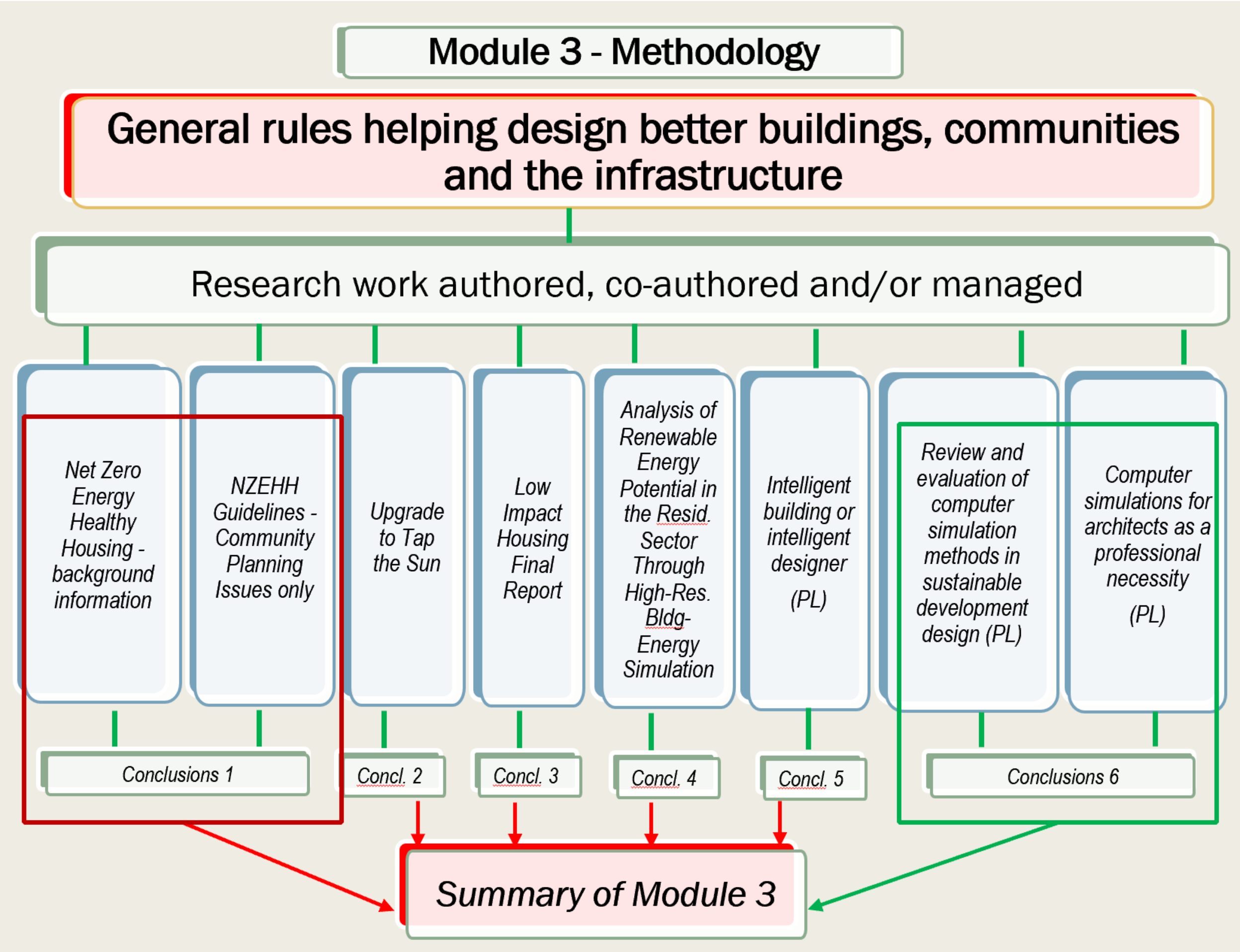


Figure 8. Methodology of Module 3. Source: author's own study

This module contains the comprehensive background information for high-performance housing initiative in Canada called EQuilibrium™ followed by the detailed guidelines and protocols related to both buildings and urban planning in the form of community-specific measures and guidelines (***Conclusions 1*** p.20). Similar document describing every aspect of the solar dependent design was developed as the update to decade-old very popular publication”Tap the Sun” (***Conclusions 2*** p.26). As a proof of low-impact housing built and operating as planned, a report is presented analyzing in a standardized way 24 case studies from Canada, Europe and Japan (***Conclusions 3*** p.30). The reality aspect of any use of solar technologies across Canada was researched with the primary goal to provide a technical assessment of the potential of renewable energy systems in low-rise housing. (***Conclusions 4*** p.34). Such process must take into consideration the current, and future technologies and decision have to be made how the future operations will be managed through the building intelligence

(***Conclusions 5*** p.36). The Integrated Design Process (IDP) requires the use of the energy simulations especially with high-performance buildings and that necessity was analyzed and shown (***Conclusions 6*** p.41).

3.3.2. Summary

Various initiatives and programs offer to building and community designers the opportunities, by managing loads, to relieve the infrastructure during heat waves or cold snaps, and to avoid having to pay peak rate energy costs. Such situations also trigger utility brownouts/outages or spikes that can be avoided using renewable energy and backup power capabilities that appear suitable for both large cities and smaller communities.

The infrastructure, size of which depends on the buildings operational requirements, must be built and maintained with its other parts with different but not lesser importance such as water drainage, stormwater, electrical services - lighting, traffic light and other.

The building contribution depends on the various strategies and techniques but also on the specific context – the immediate neighborhood and then the urban pattern. The poor solar planning, site related, is a primary issue impacting the integration of solar thermal and PV. The use of solar power became a staple within the progressive architecture, but often, regardless of jurisdiction, successful implementation of solar measures still depends on external subsidies.

Planning densities and design goals in the Net Zero Energy Healthy Housing (NZEHH) approach promote solutions that adequately balance occupant's needs and desired activities with community needs and functions. Building materials are specified from local renewable resources; construction waste is reduced and well managed, construction impact on the surrounding area and watershed is reduced through reduced erosion and durability of building components is emphasized. The proposed housing uses efficient water and wastewater systems, and site design and landscaping provide for on-site rainwater use, stormwater retention and reduced infrastructure costs. The designs can minimize the need for raw materials extraction - be it forest-, petroleum- or water-based resources, thus the environmental impact of housing. It will require new approaches to community planning, housing design, materials selection, construction techniques and the regulatory approvals process as well as the integration of processes.

Through a combination of innovative design, and state-of-the-art equipment, the optimized design can significantly cut the operating energy consumption, and with the use of "smart" technologies, it can reduce peak demand by shifting some electricity demand from high-use to low-use periods.
It is possible to incorporate Energy Elasticity & Resiliency (not just Fuel Switching) by cooperation, conservation and sharing at the community level, for example, the surplus heat/ cold/power can be available from nearby commercial / municipal facilities (supporting the idea of Synergy Zones mentioned in).

One of the best ways to reduce the demand for potable water and the production of wastewater is by improving the efficiency of water use that can come as the result of changes in habit, others in changes to hardware (the use of water meters can cut residential water use by at least 30 to 50 percent) as well as to use appropriate water quality for intended purposes. Outdoor residential water use can be significantly reduced by employing alternative landscape designs – like Xeriscaping requiring the minimum amount of maintenance and irrigation. Use of permeable hard surfaces designed for infiltration is essential for enabling trees and other plants to get the water they need and for reducing stress on municipal stormwater systems.

Stormwater from large paved sites and roof areas has severe impacts on local ecosystems (oil accumulation, erosion of natural water-courses and flooding of treatment facilities) and municipal systems (storm sewers are sized for peak periods) and proper stormwater management can reduce stress on the sewer system. Grey water is still a subject of concern even after all measures of water saving due to a need of treatment and separation of it in plumbing systems should be considered.

The thesis is also supported through the subjects related to transportation where impacts of buildings are not only about indirect transportation emissions, but from the built infrastructure such as highways, feeder roads, streets, all of which must be constructed and maintained in a long-term with all other services such as water drainage, stormwater management, electrical services - lighting, traffic light, overall controls. The infrastructure must survive winter, and that means huge expenses in snow clearing and extensive repairs every year to the majority of roads due to “freeze and thaw” cycles.

Integrated planning of sustainable neighborhoods/communities can provide significant benefits and reduced costs. Analyses followed by the optimization of buildings and the area they are built on can create opportunities for energy and water integration as well as the use of renewable energy and waste within the community systems. District-scale development planning can also facilitate pedestrian-friendly alternatives such as walking and cycling routes as well as better developed public transportation. The resulting satisfaction translates into the better understanding of the environment leading inhabitants to live better, pay attention to the resources they use, they save, and look after. That is an impact of buildings in which people care about what they have.

The new housing should be designed as flexible housing to accommodate changes in occupancy over its lifetime while making the best use of the investment in both the housing and the infrastructure of existing residential neighborhoods. “Tap the Sun” publication provides achievable solar goals for typical situations, with guidance for further explorations. It also tells how to design a house with passive solar design, an energy-efficient envelope, appropriate technology and provides examples for every climatic region in Canada.

The use of solar power in all aspects of it became a staple within the design circles of progressive architecture. With clear guidelines for What and How to do it, the architects can quickly follow the path, making sure that their efforts also go towards the adjacent, almost always indispensable and essential, infrastructure. Very often such measures are unnoticed, being almost automatic- the water saving reduces the size of plumbing systems as energy conservation reduces HVAC system’s size.

However, all still depends on the sound design and the will of designers to pursue the goals.

While looking at world examples of the low -impact housing several conclusions seem to be very relevant to the building contribution to infrastructure, such as the poor solar planning with the insulation "replacement", integration of solar thermal and PV into the building envelope resulting in a better quality/cost ratio, successful implementation of solar measures still often remaining dependent on external subsidies

The overall primary conclusion from this "worldwide" research is that there is a need for benchmarks, references, clearer guidelines and goals, as well as criteria for overall green performance ratings as it may be difficult to assess with confidence and consistency.

The assessment of the potential of renewable energy systems in buildings is crucial for the long-term urban planning and assessments of needs, and that means the opportunities that also impact on the existing or future infrastructure. In the context of the thesis, various scenarios were analyzed under the angle of the potential building contribution. The level of research was beyond a particular building and its design; however, its usefulness was unquestionable, as it merely shows what could be viable in any particular location in Canada and the research, as such, may be used by the policymakers on a national scale in any location in similar climatic zone and economy.

The research concluded that without substantial reduction in the overall energy demand, in both electricity and thermal, the solar technologies may not meet the energy demand in the residential sector and the incorporation of all measures is recommended. Thus, such a conclusion supports the thesis that the buildings can supply the energy complementing the existing grid; however, the total dependence on renewable sources would not be possible in the near future unless using all measures available and perhaps on a global scale.

The research established background information for similar studies that, when combined with high-quality energy simulations, can give the best results within the predicted performance of buildings. Such data is then used to establish the infrastructure capacity which, by default, is then optimized on a scale of a neighborhood or a community with all measures analyzed through the building design process.

The architects can quickly follow the solar path if they have clear guidelines, making sure that their efforts also go towards the adjacent, always indispensable and essential, infrastructure. If significant reductions in purchased energy are not possible through increased insulation levels and significant mitigation of air leakage, they may happen with configurations of zero energy/emission mechanical systems (high-efficiency geothermal, solar thermal and PV). However, such ideas are in apparent contradiction with the elementary statement that "first the best design and only then technologies, if needed at all."

Other features of sustainable infrastructure such as green roofs, permeable sites, minimized building footprint, maintained trees, and restoration of degraded areas are all "a must" in sustainable design. Good design should minimize storm system infrastructure and also increase the amount of permeable surface on the site. To facilitate the concept work, the benchmarks, references, clearer guidelines and goals, as well as criteria for overall green performance ratings are needed.

"Intelligence" is the future of the buildings, with the ultimate goal of health and comfort of the user and the protection of the environment. It allows to manage the operations of the built environment such as buildings and the infrastructure and by that also the entire construction process requiring the building of the roads with the entire accompanying infrastructure and fuels polluting the eco-systems.

Simulations create the opportunity to evaluate many solutions and choose the option that best meets the requirements or goals. Thus they can significantly improve the quality of the building and determine the contributory side of buildings towards the infrastructure. The disaster or climatic event scenarios can also be simulated on models exactly corresponding to real buildings and real cities and their surroundings by default related to the infrastructure.

Simulations are the indispensable tool in determining the contributory side of buildings towards the infrastructure and can also evaluate it from many perspectives vital for either extension or reduction and analysis of its behavior under given or required circumstances.

An example would be projections of catastrophic events, where the most improbable disaster scenarios are simulated on models corresponding to real buildings and, in turn, to their surroundings by default also related to the infrastructure. Similar simulations are conducted in relations to the climatic events and their effects on the built environment including the site related infrastructure where the disasters like Sandy, Katrina and similar calamities can be shown as examples.

Simulations scenarios developed through the design development process should be based on an Integrated Design Process (IDP), the crucial element in any design of a significant size. The use of an IDP from the moment of the project inception to the commissioning of a net zero or net-positive energy building will contribute, in turn, through its extreme energy and water efficiency goals, to the reduction or elimination of the infrastructure we know. A primary requirement of the IDP is to optimize the technical installations in the design through the correct choice of form, function, structure and construction products and by following the principle "as little technology as possible, just as much as needed," to substantially reduce construction first and then operation and maintenance (O&M) costs that are all related to energy and water in all forms, thus to infrastructure.

Simulations are also crucial in cost projections where different scenarios are analyzed through all phases based on an Integrated Design Process during which a life cycle cost analysis has to be completed. The components of such analysis should be reasonable and realistic, and the estimations should be supported with appropriate simulations and documentation.

3.4. Impact of urban design on municipal infrastructure - *Module 4*

3.4.1. Introduction and Content

The purpose of this topic was to gather the type of information that could help visualize the locations and their contexts with already implemented right (or wrong) principles of urban design on a scale of neighborhood or community. Urban design and development do not exist without buildings that are built in the urban context – specific urban planning ideas that are presented in this module aiming at the improvement of all aspects of the urban life while affecting the infrastructure in many, well described, manners.

The objective of the Water-Sensitive Urban Design is to integrate urban design with natural ecological processes and add value to the development of scale with its water infrastructure (***Conclusions 1*** p.9). Other various approaches are being taken to mitigate the deterioration of urban environments that are responsible for the creation of heat islands and their effects on health (***Conclusions 2*** p.16).

Integrated planning on a scale of neighborhood or community can provide significant benefits and reduced costs while the optimization of buildings and the surrounding area can create opportunities for energy and water integration as well as the use of renewable energy and waste within the community systems. The measures in design settings from urban regeneration to advanced communities are provided and analyzed (***Conclusions 3*** p.32). The project about Green Islands, as part of local agenda 21, shows the opportunities and methods of "city naturalization" with a simultaneous promotion of specific approaches to nature and the society to be used by local community involved in managing unique landscapes (***Conclusions 4*** p.35).

In both urban and building aspects, measures planned and applied to Angus Technopole Locoshop directly affected the entire site and its infrastructure. With the community pressure, all objectives were achieved including energy efficiency, optimized environmental aspects, water use and treatment, recycling and reuse of most materials, saving on resources and, indirectly, on production and transportation of materials. Most of these aspects directly influence the capacity and operations of the infrastructure by contributing to it. (***Conclusions 5*** p.40).

The Beaver Barracks charrette demonstrates the advantages of engaging a wide variety of stakeholders in the conceptual design of development projects with the benefit of almost all aspects of the building design as well as the neighborhood playing a role in the contribution to the required and operating infrastructure. (***Conclusions 6*** p.44).

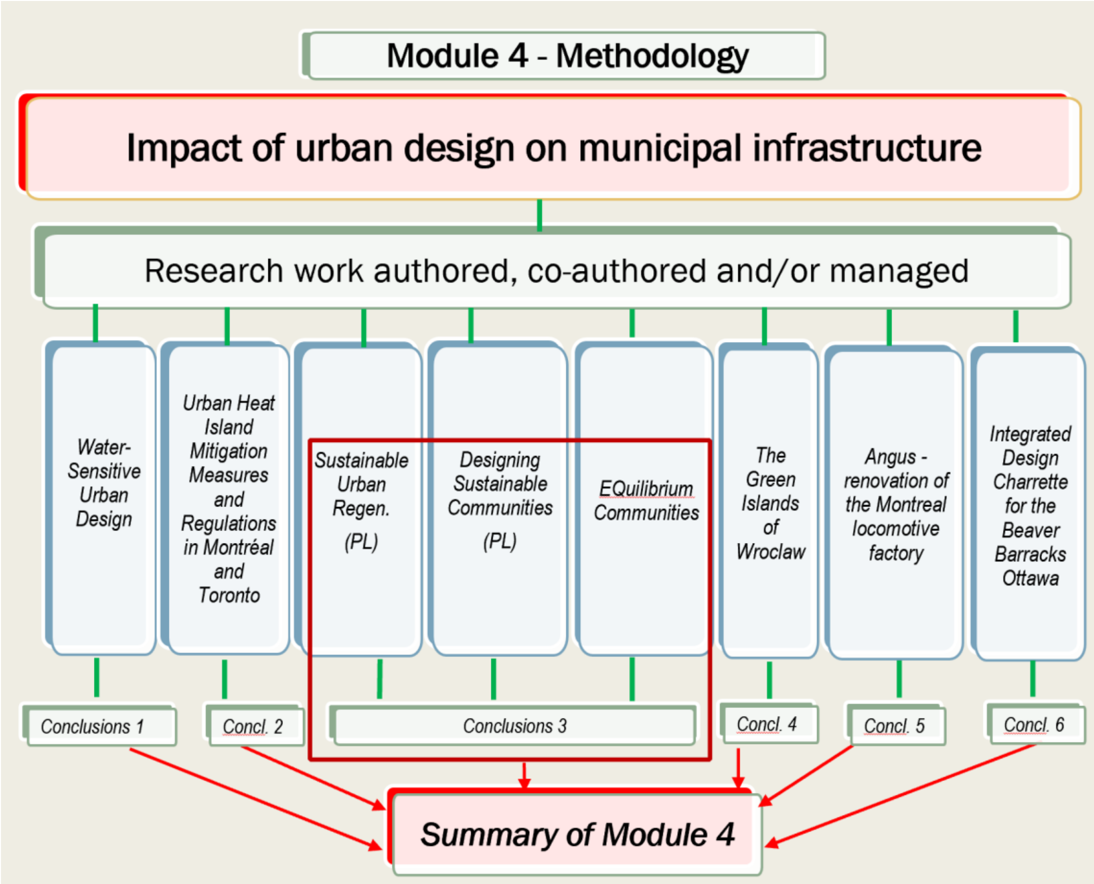


Figure 9. Methodology of Module 4. Source: author's own study

3.4.2. Summary of Module 4

Water touches all aspects of our lives, and thus should touch all aspects of our design. The objective of the Water-Sensitive Urban Design (WSUD) is to integrate urban design with natural ecological processes and add value to the development of scale with its water infrastructure.

In other more scientific words:

to ***maintain or replicate the pre-development water cycle through the use of design techniques to create a functionally equivalent hydrological landscape*.**

Various positive approaches are mitigating the thermal deterioration of urban environments. Conserving existing green spaces in urban settings, using more appropriate materials in the built environment, opting for designs that address both the issues and their impacts, reducing impermeable surfaces and developing a better public transit policy should reduce the presence of urban heat islands and affect the infrastructure directly.

The impact of urban heat islands can cause temperature raising in cities by 2 degrees C stronger than in other, non-highly urbanized areas. That means a much higher demand for air conditioning, thus energy, and general problems such as, for example, lower productivity and high vacancy rates resulting from the lack of comfort satisfaction but affecting the operations and stability of the infrastructure systems.

To combat heat islands effectively, the simultaneous introduction of various mitigation measures is the most efficient approach with early adoption of measures and with specific attention paid to commercial and industrial sectors. Implemented measures produce benefits such as lower surface and felt temperatures, reduced mortality, better quality of life, less smog, smaller temperature variances, the longer useful life of materials, energy savings, higher property values and fewer floods.

Design of any infrastructure requires a thorough analysis that will directly affect the size of the piping network, layout and surfacing of the roads, the design of buildings, elevation of buildings (flood risk), nature of the landscaping and the density of the development. That is a direct impact on the infrastructure of any building, be it a single one or a cluster of them, or the entire neighborhood.

The Canadian NZE Healthy Housing Initiative’s approach protects and conserves natural resources through the planning densities and design goals promoting solutions that adequately balance occupant’s needs and desired activities with community needs and functions. Building materials are specified from local renewable resources; construction waste is reduced and well managed, construction impact on the surrounding area and watershed is reduced through reduced erosion and durability of building components is emphasized. NZE Healthy Housing uses efficient water and wastewater systems, and site design and landscaping provide for on-site rainwater use, stormwater retention and reduced infrastructure costs.

Alternative designs can minimize the need for raw materials extraction — be it forest based, petroleum based or water related resources. More efficient construction processes can reduce wastage on the site. Minimizing the environmental impact of housing will require new approaches to community planning, housing design, materials selection, construction techniques and the regulatory approvals process as well as in how these processes are integrated.

Sustainable community is a community that supports healthy ecosystems and healthy living conditions, and offers a variety of types and sizes of buildings, social, educational and cultural facilities. Full diversity of land use, commercial and service opportunities along with public space, and easily accessible, connected and affordable communication systems.

Designing it requires an interdisciplinary design team working as part of an integrated design process that involves a broad involvement of the community and stakeholders. Designing on the neighborhood scale gives the opportunity of integrating various systems in micro- and macro-scales. Responsibility should be borne by designers who also have an excellent opportunity to discover new ways of creating architecture and urban planning.

Integrated planning on a scale of sustainable neighborhood or community can provide significant benefits including costs. Analyses with the optimization of buildings and the area around can create opportunities for energy and water integration as well as the use of renewable energy and waste within the community systems. District-scale development planning can also facilitate pedestrian-friendly alternatives such as walking and cycling routes as well as better developed public transportation.

At the scale of a community, it is necessary to include social aspects that are reflected by the satisfaction of translating into a better understanding of the environment that leads inhabitants to better, healthier life. Such an approach goes than to the infrastructure as a direct impact of buildings in which people save energy and water energy and care about waste while biking to their workplace

The design requires extensive community engagement and stakeholder involvement with a thorough understanding of the relationships between the diverse elements and functions of the built environment and seeks to capitalize on the interconnections between elements and systems (e.g., waste from one area providing fuel for another).

Designing at the neighborhood/community scale provides opportunities to integrate systems (such as water and energy systems) across multiple buildings and land uses. The infrastructure always benefits from such actions, and sustainable community projects in Canada and elsewhere demonstrate that specific, mentioned above, principles apply universally, although they are, or should be, interpreted locally to suit the particular context of the neighborhood or community. Communities that are designed with these principles can, in relation to the impacts on infrastructure significantly reduce energy and waste, reduce demand for urban resources and preserve ecosystems.

Minimizing the environmental impact of housing requires new approaches to community planning, housing design, materials selection, construction techniques and the regulatory approvals process as well as in how these processes are integrated.

Many municipalities are finding increasingly difficult and expensive to keep up with the growing requirements for fresh water and sewage treatment facilities and each measure that reduces water demand, also reduces infrastructure needs.

The Angus Technopole project in Montreal, the result of collaboration between governments, the private sector, associations, and experts, is the first industrial redevelopment with a green building approach in Canada. Main development criteria included marketing the Locoshop as the flagship of the Technopole, planned with the principles of sustainable community development sensitive to the existing urban context and to develop a building concept within its economic, historical and social contexts, at a competitive cost.

All measures applied to Angus Technopole Locoshop directly affected the entire site and its infrastructure. With the pressure of the community, all objectives were achieved including energy-efficient green building, optimized environmental aspects, water use, treatment, recycling and reuse of most materials, saving on resources, and indirectly on production and transportation of materials. Most of these aspects directly influence the capacity and operations of the infrastructure by contributing to it

The Beaver Barracks charrette, another example of an integrated approach, demonstrates the benefits of engaging diverse stakeholders in the conceptual design of the development project. Through the consultative nature, different interests, opinions, concerns, and solutions can be discussed and considered in the design of buildings and communities. The charrette helped the owners identify technologies and practices improving the overall sustainability of the project well-integrated into the existing neighborhood. The example of such a process is the proposed energy system -a central, community geothermal system that would provide all of the buildings on the site with space heating, space cooling, and domestic hot water. The decision was taken after a thorough analysis of the feasibility study and test drilling carried out by a micro-utility company that confirmed the costs and benefits.

Almost all aspects of the building design, as well as the neighborhood itself, play a role in the contribution to the required and operating infrastructure. Thanks to the process every feature was well studied and the overall results showed that both energy and water consumption could be significantly reduced and directly contribute to the development's infrastructure. Parts such as the green roof are contributing to the stormwater services and indirectly to the transportation emissions with some vegetables growing there.

In the urban context, the site plan determines how the building interacts with the surrounding neighborhood and environment. Careful site planning can contribute to the efficiency of the individual building (including optimization of its location, orientation, and landscaping), minimize the impact of it on the surrounding environment including its infrastructure and contribute to a 'healthy' social environment.

3.5. Other potential influencers – *Module 5*

3.5.1. Introduction and Content

This part consists of mostly urban issues that do not belong elsewhere, due to the fact of not being written or managed by the author, and serve as the "other" update and research support to the thesis. Those issues are Synergy Zones with microgrids, urban agriculture, hybrid infrastructure, climatic design, insurance issues and the Big Data involvement in all aspects of a global image of the built environment that cannot exist without its bloodstream - the infrastructure.

The urban morphologies depend on density, streets network and energy consumption of the built environment and the urban geometry is an essential factor in energy-optimized architecture.

The most important factors besides the local climate, affecting the amount of available daylight are the ratio between the building heights and the street width between buildings, a reflectance of the exterior building materials and ground surfaces, and the area of windows [DeKay, 2017] (***Conclusions 1*** p.14).

The potential role of small urban areas offers possibilities to improve the performance of buildings. Such concept model that builds on the form of synergy in energy, emissions and water and other less critical issues, is called a Synergy Zone. It fits well with the idea of a hybrid infrastructure either complementing it or creating the new synergies (***Conclusions 2*** p.22).

Part of a green infrastructure system consists of Low-Impact Development (LID) practices (such as stormwater management, stormwater runoff volumes, green roofs, permeable pavements, soakaways) and landscape best practices include other infrastructure related measures. The related design principles for urban agriculture provide, in turn, a framework and context for more detailed design strategies (***Conclusions 3*** p.27).

The most infrastructure relevant climate events are floodings and to mitigate or avoid the disasters the urban and building designs should be carefully planned with all climatic factors considered. Life cycle costing (LCC) helps to look beyond initial capital costs and can assess infrastructure strategically over its entire life significantly strengthening fiscal performance.

Almost every aspect of life today is analyzed with the use of the Big Data, and it also applies to the aspect of buildings and their operations - all to improve the overall performance of the built environment (***Conclusions 4*** p.32).

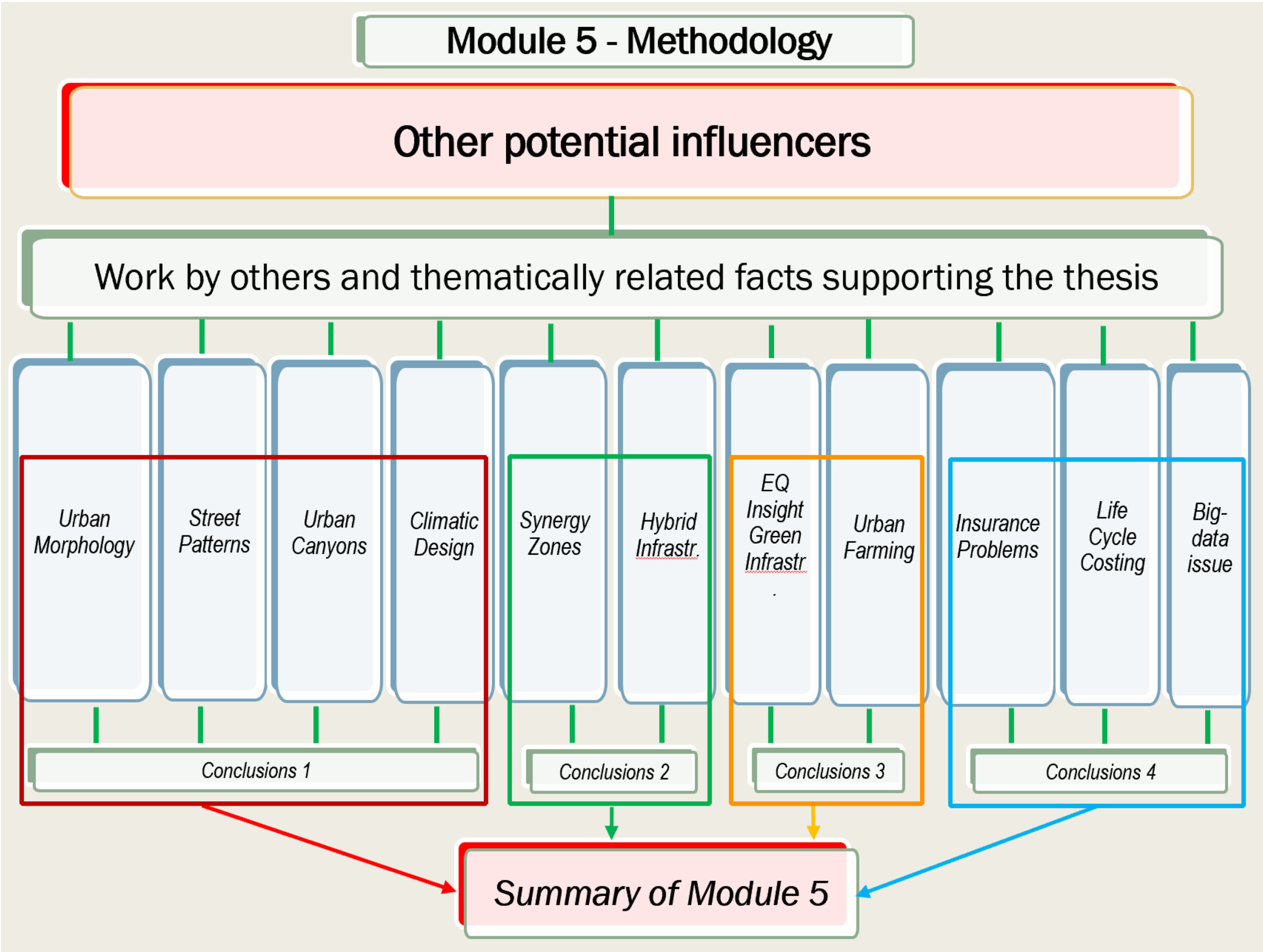


Figure 10. The methodology of Module 5. Source: author's own study

3.5.2. Summary of Module 5

"Urban" means a planning pattern, characteristic of the highly populated area with infrastructure; however, it may be applied from a specifically oriented building to a block, neighborhood, community, district, city, and agglomeration.

One of the most fundamental questions in urban planning and building regulations is how to secure universal access to sun, light and fresh air, all affecting the energy use of buildings and related infrastructure. Optimization of energy in the building and urban designs in ever-growing cities requires an understanding of all interrelations between them, and the conclusions strongly support the thesis that buildings, if adequately designed within equally well thought off urban context, are major contributors to the infrastructure.

Urban geometry is an essential factor in energy-optimized architecture as energy savings from an urban design are very long-term while reducing the need for costly but not durable technologies.

Urban context, an important contribution to the building energy demand, is often overlooked in favor of individual building performance [after DeKay, 2017].

A study of urban fabric was performed by analyzing those aspects of spaces with a range of parameters such as building sizes and shapes, street patterns and shapes, the urban design itself and a population density. Unobstructed passive volume uses two times less energy than the non-passive volume and an efficient building in an efficient urban fabric can consume four times less energy than a non-efficient one [after Salat, 2008].

The overall energy consumption of buildings depends in part on available daylight to provide the required level of light, thus directly affecting the infrastructure loads [after DeKay, 2017].

The most important factors besides the local climate, affecting the amount of available daylight are the ratio between the building heights and the street width between buildings, a reflectance of the exterior building materials and ground surfaces, and the area of windows [DeKay, 2017]

The name - urban canyon- has been used in urban climatology describing, in geometric terms, the height to width ratio of the space between adjacent buildings. The link between urban density and building energy use is an intricate balance between climatic and spatial factors, material and urban use patterns with buildings that constitute them [after J.Stroemann, P. Sattrup, 2011].

Local streets create main road network within a community and become a major determinant of the designer's input in buildings and infrastructure in any urban development. The outcomes of other presented studies only confirm such relations as, for example, the design of permeable areas that decrease stormwater systems, contributing positively to the urban heat island effect by lessening the energy demand for cooling and increases urban comfort.

Well-designed streets can also mitigate traffic and enable active transportation (walking, cycling), which can reduce the energy required for transportation and related GHG emissions. Even minor adjustments to street patterns can create opportunities to build higher density developments and reduce the impacts on municipal infrastructure while raising the viability of shared energy systems.

The potential role of small urban areas offers possibilities to improve the aggregate performance of buildings. A concept model that builds on the form of synergistic performance in energy, emissions and water and other less critical issues, is called a Synergy Zone. A more extensive range of issues provides an appropriate framework for neighborhood infill and renovation programs strategies with very high levels of performance. They include the use of renewable DC power with minimized conversion losses, the distribution of thermal energy from buildings with a surplus to those with deficits, and similarly more efficient use of surplus greywater. [Larsson, 2012]

The performance synergies can be achieved within mixed-use buildings in urban settings, such as different schedules within each occupancy for peak electrical or space heating or cooling demand. It is especially valid if the scope extends from a single building to small clusters of buildings, where the area of a cluster to be small enough to allow economical active thermal transfer between buildings and to allow direct use of DC power to buildings in the cluster.

Hybrid infrastructure is defined as systems that are integrated within buildings and landscapes that also provide non-infrastructure uses [after Mangone].

Hybrid infrastructure can improve the economic performance of municipal infrastructure.

District heating and cooling systems (DHC), particularly when combined with district energy systems (DES), can be more effective than individual building mechanical systems. That may happen with regards to cost, energy performance, and emissions, as well as reduction of the building floor area dedicated to building systems, thus contributing directly and indirectly to the reduced required capacity of the infrastructure that serves the construction and operation of the smaller building [after Mangone, 2015]. However, it would not result in the reduction of the overall neighborhood infrastructure size.

Specific technical infrastructure features can be designed to improve occupants well-being, such as, for example, designing part of a neighborhood rainwater storage system as a falling water feature with sounds and light - both stress and anxiety relievers. Water tanks can also function as thermal mass and shade for a building and, depending on a context, can substantially improve the thermal comfort of a building space, optimize occupant's satisfaction resulting in much more cautious approach to the use of energy, thus positively affecting infrastructure's size and usage [after Mangone, 2015],

For the functioning of any modern urban area, critical infrastructure is necessary, such as hospitals, public transport, food supplies, water and sewage facilities which should operate at a basic level in all extreme conditions.

The Synergy Zones concept can meet the emergency supplies; the hybrid infrastructure shows that it can be resilient, redundant and modular providing the same, similar, or backup functions. Using both concepts can result in a significant victory over the climatic or other unexpected events.

Part of a green infrastructure system consists of Low-Impact Development (LID) practices (such as **stormwater management**, **stormwater runoff volumes, green roofs, permeable pavements, soakaways).** Landscape best practices include other infrastructure related measures such as design which minimizes the need for irrigation- up to the elimination of the water pipe network, maximization of tree canopy- shading leading to energy savings, pedestrian-oriented routes, streetscapes and open spaces – minimization of car traffic.

Design principles for urban agriculture provide a framework and context to guide more detailed design strategies aiming to create an infrastructure that celebrates food production, preparation, and consumption and leads to diverse, productive landscapes. The technical considerations, such as structural implications for planters connected to buildings and green roofs, the need for irrigation systems, the balancing of rain and stormwater systems regular needs with a natural capability of urban farming to absorb part, if not all of it, are taken into the account when buildings- future contributors are designed [after Gorgolewski et al., 2011].

The potential contribution of designs linking spaces like riverbanks, median strips, public parks, schoolyards and boulevards with the urban agriculture of buildings and communities - the transformation of “lost,” or simply underused, urban space containing buildings [Rovers, 2006] could have a huge impact on the infrastructure. Urban farming can become the remedy for increasing food demand, a solution to the increasing urban areas with no green spaces and a relief in the age of global warming. Buildings in such cases can provide direct benefits such as, for example, an improved thermal performance due to green roofs and green walls acting as insulation buffers, so acting as an infrastructure contributor. Furthermore, the major advantage of rooftop gardens is that they cut on the transportation energy as they are not generally used on a commercial scale.

During upgrading sewers and storm-water infrastructure parts of their systems that are at the highest risk have to be identified. The outcome is related to the design of buildings and thus inherently the built environment -urban tissue that results in better planned and built infrastructure while creating another aspect of buildings and community performance.

"Cities are going out to engage their citizens. It is not just infrastructure; homeowners also have to take measures to protect their property."

Life cycle costing (LCC) helps local governments look beyond initial capital costs and can assess infrastructure strategically over its entire life, significantly strengthening fiscal performance. It is especially useful for evaluating premium efficiency infrastructure and renewable energy opportunities since their initial costs are often higher, but they tend to have lower operating and maintenance costs over the life of the project. A major barrier is that consumers focus on the initial capital cost and simple payback and LCC, rather than evaluating projects on the first cost, considering the total cost of owning, operating and maintaining infrastructure over its utilitarian lifecycle. LCC has applications across a wide range of sectors with the following related to the infrastructure

- Civic Buildings, relevant for premium efficiency targets for new and existing stock
- Equipment, relevant for office equipment and machinery
- Infrastructure, relevant for transportation and energy systems
- Land use planning, notably as it pertains to infrastructure costs
- Residential and Commercial Buildings

CMHC created its Life Cycle Costing Tool for Community Infrastructure Planning to help owners and developers estimate the approximate costs of development and **to compare alternative development- different options for types of infrastructure[7].** Reduction of potential costs of a road

[7] It is available at http://www.cscd.gov.bc.ca/lgd/greencommunities/sustainable_development.htm Accessed in March 2018

network can switch funding towards building performance improvements impacting on infrastructure. Every aspect of life analyzed today is with the use of the Big Data[8] - sourced from sensors, satellites, digital pictures and videos, banking records, cell phones, GPS signals, climate data, wireless networks; every bit of exchanged data in our daily lives is part of analytics. It also applies to the aspect of buildings and their operations affecting the infrastructure from monitoring controls through management on all levels. Control strategies include the continuous performance assessment of the building, market conditions, operational statistics- all to improve the overall performance of the built environment [Sood Joshi, Desormeaux, 2018].

[8] S.Sood Joshi, C. Desormaux, "How has the Big-data altered our built environment?", students of Eco Design, Green Architecture, Algonquin College, Ottawa, Canada, 2018, *W.Kujawski, course professor*

III. BUILDINGS AND THEIR OPERATIONAL PARTNERS AT WORKS

Motto: **"We shape cities and cities shape us."** - *Winston Churchill*

1. Different aspects of buildings connections[9]

Many of the building developments, while acting as infrastructure, can either reduce their impact on community infrastructure or eliminate entirely the need to connect to its elements such as electricity grids or municipal waste and stormwater systems. However, such connections could play a very positive role when the infrastructure play a role of a newly created connector-supplier of energy and water from the adjacent mixed-use or industrial neighborhoods.

The second aspect is the use of a new expression of the "hybrid infrastructure" defined as system integrated with buildings and outdoor systems[10] - landscape architecture that also provides off-infrastructure services while contributing to local sustainable development. This innovative idea is introduced in the dissertation as a part of the interaction between buildings and their infrastructure "surroundings." An example of it is a wastewater treatment system within a high rise office tower that can filter the wastewater of the building occupants, as well as additional wastewater from the municipality from a nearby city sewer [Mangone, 2015].

Synergy Zones [Larsson, 2012] is a plan to create a system model for the development of new or revitalization of existing small urban areas and to optimize all elements related to buildings and also indirectly to the services they provide [Larsson, 2011].

The two ideas of Zones and Hybrid, although not entirely new, attempt to redefine by the update to the 21st century standards, an old concept of infrastructure making sure that both can have a significant and interchangeable impact, as they complement each other on a new perspective on infrastructure and thus, indirectly, on the overall conclusions of this dissertation.

Two important ideas are synthetized: Smart Grids – optimization of supply and demand of electrical power at a regional level, and a Synergy Zone dealing with the interaction of other issues such as:

- Thermal energy for space heating or cooling;
- Domestic hot water;
- Grey water;
- DC power at the zone and building level;
- Solid waste generated by building operations.

Each of these urban sub-systems could benefit from appropriate storage systems, a method for optimization of supply and demand, and distribution networks.

---

[9] That section is partially based on the article "New role of buildings as contributors to the infrastructure", Technical Transactions 9/2017 https://suw.biblos.pk.edu.pl/resourceDetailsRPK&rId=68744 accessed May 2018

[10] In order to be considered as a hybrid infrastructure, such system(s) must provide a greater quantity of infrastructure services than the quantity of services that are required by the individual building or landscape, and their occupants.

Tillie et al. developed an inventory of a wide range of buildings, with different cooling/heating needs patterns changing throughout the day and the year. With an appropriate mix of buildings (a heating/cooling ratio close to one) and heating/cooling storage facilities at the neighborhood scale, the waste streams could be reused, thus this process could theoretically lead to almost 50% reduction in energy consumption for heating and cooling: as all the heat usually wasted by cooling systems is reused, heating could be almost “free”[Tillie et al, 2009]

.

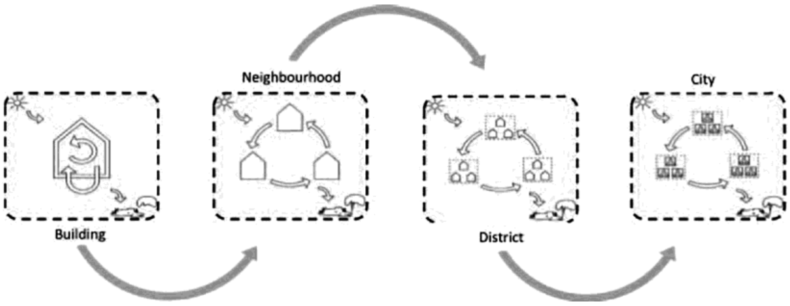


Figure 11.Knotting the flows at every scale . Source: Tillie et al, 2009

Such strategies could be implemented to building, neighborhood, district/community, and even the whole city itself while reducing energy consumption, applying reuse and exchange of waste energy and production of renewable energy [Fig. 11], [Fig.12].

Since heat is a natural byproduct of many manufacturing processes, some developers have sited residential, office or other types of buildings close to industrial or manufacturing plants to take advantage of district heating systems. The Maplewood district of North Vancouver [refer to Fig.30 p.80] built an entire community plan around this concept by integrating eco-industrial networking with sustainable community planning.

Buildings that supply their own energy and produce it also for others nearby are often the most cost-effective. Combined Heat and Power [CHP] systems achieve peak efficiency when they run continuously on full-time loads in their own neighborhood or community. Having also its own water treatment facility, and greenhouses they can remain functional even in times of emergency.

Scaling from the building up determines if energy can be exchanged or stored especially between buildings in the neighborhood where the diversity of uses and configurations affect the efficiencies of most systems. They usually work much better on a neighborhood scale than in a single building, therefore came the logical necessity of creation of a community of buildings connected as a system, rather than a community of separate buildings. The benefits available through different building sites go beyond the traditional infrastructure, and now, even a food production of a scale can be considered [after Larsson, 2012].

Figure 12. Buildings and community. Source: R. Bailey, 2010, Vancouver

1.1. Eco-industrial networks

So-called Eco-Industrial Networks [EIN] and eco-industrial parks are structured around both energy and waste sharing between producers and consumers and while networks usually supply entire communities, the parks, generally, share within themselves, and then almost nothing is wasted, and everything is used.

A good example of such EIN is Kalundborg [Fig. 13] in Denmark (a city first settled in 1167). It started their network in 1961 with a single power station project and had expanded it over time into a cluster of companies that rely on each other for material inputs and supply of energy to the entire community while reducing waste and improving its economics and environment. They do it for mutual benefit, on the basis that by-products from one business can be used as low-cost inputs by the others.

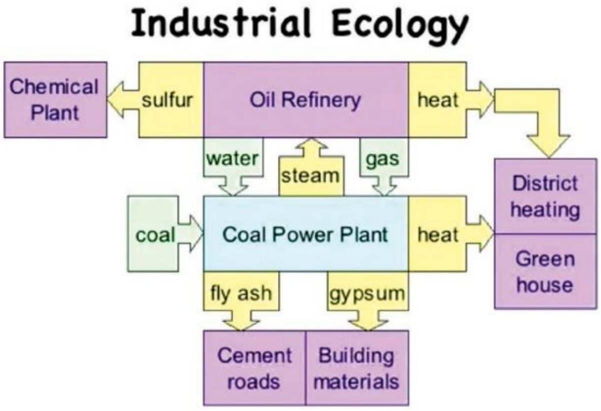


Figure 13. Idea of EIN. Source: https://en.wikipedia.org/wiki/Eco-industrial_park[access:March 2017].

Figure 14. View of Kalundborg. https://en.wikipedia.org/wiki/Eco-industrial_park[access:March2017].

For example, treated wastewater from one place is used as cooling water by the adjacent power station. Others purchase 'waste' process steam from the power station for their operations. Surplus heat from the power station is used for heating adjacent homes and warm a local fish farm. Another by-product, such as fly ash, is used in cement work and roadbuilding and to obtain gypsum; such purchases meet almost two-thirds of needs [Fig. 14].

Surplus gas from the refinery, a low-cost energy source, instead of being flared off, is delivered to others. The use for household heating of the excess heat from its producer has eliminated about 3,500 oil- burning domestic heating systems. The original motivation behind the clustering of “park stakeholders” was to reduce costs by using unwanted by-products; but soon it was complemented by a vision of environmental benefits shared by everybody thus creating, in a sense, a social outcome with a high level of occupants’ satisfaction.

1.2. Brownfield Redevelopments

Building on brownfields can be challenging due to the need for site remediation meaning significantly increased cost and bureaucratic hassle of most environmental checklists. However, it also presents several potential benefits, including prime locations, as most brownfields are within the urban core, reduced operating expenses with comparable design and construction costs because at least part of the infrastructure is already in place. There also may be funding and marketing opportunities available specifically for brownfields redevelopment with the symbolic value of leaving behind a legacy of sustainability.

BO01 (“Living 2001”), Malmö, Sweden. [Fig.15]

It is a mixed-use development with 10,000 residents on a brownfield site that contributes to the municipal infrastructure capacity by producing renewable energy and reducing stormwater runoff.

It is one of the most important and already symbolic examples because it works on a big scale while contributing to most of the infrastructure elements. BO01 was built on a former industrial site with taller buildings located on the edges of the development to shelter smaller blocks and courtyards from winds coming off the Baltic Sea. A nearby 2 MW wind facility, supplemented by photovoltaics (PVs) provides almost all electricity needs; however, a part of the energy for homes and cars is provided by methane from household waste, captured through vacuum garbage collection system. All garbage, organic waste, and recyclables are connected to the underground pipeline system sucking material to a central storage area where it is picked up by municipal trucks, reducing GHG emissions and the traffic areas.

Figure 13. Aerial view of BO01. Courtesy of the City of Malmö.

Energy for water heating comes from seawater and solar, and the heat is distributed through municipal sewage and waste infrastructure. Green roofs were installed on most buildings to absorb rainwater, cool the buildings, mitigate heat island effects and provide gardening space for residents. The roofs also lower the risk of sewer overflows and overload at the municipal treatment plant by delaying stormwater runoffs.

Southeast False Creek, Vancouver, British Columbia, Canada[11]

This project contributes to the municipal infrastructure capacity by using a district heating system with sewer heat recovery12 and providing space for urban agriculture.

Historically, Southeast False Creek (SEFC) [Fig. 16] was used for industrial and commercial purposes, but the City of Vancouver decided to transform the site into a sustainable model development. It includes space for wildlife habitat, playgrounds, and urban agriculture, and in 2010 was home to the Winter Olympics Village. At the heart of it is the city-owned Neighbourhood Energy Utility (NEU), a community energy system [Fig. 18] that provides space heating and domestic hot water. The Southeast False Creek, official development plan,[13] established a policy to minimize greenhouse gas pollution associated with new buildings in the area.

Figure 14. SEFC – view. Source: CMHC and City of Vancouver

[11] The development surpassed its goal of silver LEED by becoming the second neighborhood in the world to meet the platinum standard in 2011.

[12] Southeast False Creek Neighbourhood Energy Utility http://vancouver.ca/home-property-development/utility-facts-and-presentations-in-depth.aspx (accessed April 2018)

[13] http://bylaws.vancouver.ca/odp/SEFC.pdf (accessed April 2018)

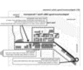
The NEU uses waste thermal energy captured from sewage to provide space heating and hot water to buildings in Southeast False Creek. This recycled energy eliminates more than 60% of the greenhouse gas pollution associated with heating buildings. The utility is self-funded: it provides a return on investment to City taxpayers, while at the same time, provides affordable rates to customers. The utility began operations in 2010 and since then has rapidly expanded to serve 395,000 m2 (4,300,000 ft2) of residential, commercial, and institutional space. Over time, the utility will be expanded to serve new developments in the neighborhood and Great Northern Way campus lands[14].

However, during the design phase, a major concern had to be addressed while modeling different scenarios: how much heat could be safely recovered without endangering the sewage treatment system and processes due to the complexity of the sewage system? It was imperative to evaluate all options available and provide the best solution.

Temperature reduction could lead to operational issues such as a buildup of fat, oil, and grease on the walls of sewer pipes, which can cause blockages and increased maintenance costs. It can also affect the wastewater treatment plants that rely on microbial processes in incoming nutrients and warm sewage to keep them active. With a significant drop in temperature, even the entire treatment process could be compromised. Considering different minimum allowable temperatures, 11 degrees C (51.8 F) was used as a minimum in the incoming sewage. Conversely, there were also concerns about sewage being used as a heat sink for cooling systems as heat would tend to increase microbial activity, leading to odors and corrosion. I

Results of the study that there is plenty of heat in the sewer system to heat homes, with the average hourly sewage temperature generally above 11 C (51.8 F) year-round. Based on winter dry weather flow, there is a total of around 45 MW of sewage heat that can be recovered to heat buildings in the city of Vancouver and around 100 MW regionwide, which could heat up to 700 high-rise buildings across Metro Vancouver. This would translate to a 200,000- tonne regional reduction of green- house gas emissions per year. Other sources for heating include rooftop solar thermal modules.

A Seniors Residency, designed as NetZero building, had waste heat planned to be delivered to its occupants from refrigeration equipment in retail spaces on the ground floor. However, the specified equipment was so energy efficient that there was not enough waste heat, but the decreased commercial energy consumption achieved the goal of the contribution to the infrastructure.



[14] Southeast False Creek Neighbourhood Energy Utility http://vancouver.ca/home-property-development/southeast-false-creek-neighbourhood-energy-utility.aspx (accessed April 2018)

Dockside Green, Victoria, British Columbia, Canada[15]

The project reduces municipal waste by using energy heating from biomass and reduces infrastructure loads with on-site water treatment systems.

The mixed-use development [Fig. 15] is supposed to produce its own heat (including hot water heating) converting wood waste into gas, eliminating fossil fuels and simply using a landfilled waste product.

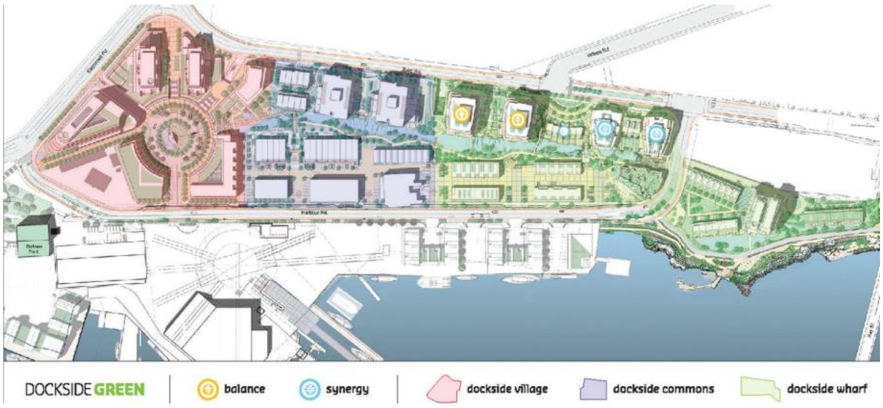


Figure 15.Dockside Green phases. Source: Windmill Developments

A communal greenway serves as both a public greenspace and a vital part of the wastewater and stormwater management system, in which stormwater is flowing to the greenway [Fig. 20] is filtered and added for reuse for toilets and irrigation. Water-saving appliances and fixtures are reducing the need to draw potable water from municipal supplies.

The 2008 crises have stopped the development [Fig. 22] for several years at 22% of expected density [Fig. 21] and it restarted only in 2017 with a modified plan, which calls for another 100,000 m2 of development and 1,000 residential units in buildings preserving, however, most of the environmental features planned in their original version.

Figure 16. Greenways. Source: Windmill Developments

[15] http://docksidegreen.com/ accessed May 2018

Design Reality check

Figure 17. Phase 1 Design. Source: Windmill Developments

Figure 18. Phase 1 in 2016. Source: GoogleEarth, accessed Feb 2017

EQuilibrium TM Community examples

A key objective of the EQuilibrium™ (EQ™) Communities Initiative was to share lessons learned from the analysis and implementation of new design approaches and technologies in the projects, and it resulted in a summary on the subject of green infrastructure. It contains specifically stormwater practices for Low-Impact Development (LID) and landscape best practices, such as habitat protection.

The systems adopted in each project are unique and context-specific. Rather than taking a "**one-size fits all** " approach, the practices in each project are unique and customized to their site conditions, context, future occupant needs, budgets and regulatory environment.

For example, the design of Ty-Histanis on Vancouver Island, British Columbia, emphasizes habitat protection and re-establishment, whereas, for the other projects, there was no existing habitat and few, if any, trees along with very limited space for habitat creation. In the denser projects, such as Regent Park below, every surface had to be optimized for vegetation, permeability, and reduction of stormwater runoff and pollutants. For dense projects like these, practices such as green roofs and permeable pavers form an integral part of the design. Each project integrates the stormwater and landscape practices into a system, working in harmony with the buildings, infrastructure, open spaces and surrounding context. They all minimize hard surfaces, for example, by limiting surface parking, and all aim to maximize the tree canopy and vegetated surfaces.

All these measures are impacting the infrastructure requirements from the size of water and sewers piping to the reduced energy demand, to the irrigation from captured water and benefits from the optimized urban design. The EQ™ projects below can serve as examples of community development at the highest level.

EQ™ Communities project – Regent Park, Toronto, Ontario, Canada

This project adds to the municipal infrastructure capacity by using a district heating plant. It also has the potential to generate electricity from renewable sources in the future.

Figure 23. Regent's Park today. Source: CMHC, 2013

Figure 24. Regent Park's 22- story building with district heating plant. Source: D. Pollard

Regent Park – Canada's largest and oldest publicly funded community, the complete redevelopment of a 50-acre site in downtown Toronto. The site was a rundown area with a low-rise and low-rent apartment buildings with a lot of social problems. Today it is a mixed-use development of social and market housing, [Fig. 23[16]] including over 1,000 homes in the form of townhouses, mid- and high-rise apartments, either market condominiums or affordable rental units for low- to moderate- income residents, and nearly 5,000 m² of commercial, retail and community space. Each building is built to LEED Gold standard. The mixture of uses, with their differing peak loads, is important, as indicated in the Synergy Zones concept, for maintaining a required constant load demand for the Combined Heat and Power (CHP) system.

The redevelopment included a natural gas-fired district heating plant integrated into the first 22- story residential tower, which is situated next to the central greenspace [Fig. 24]. The plant produces high- efficiency heating and cooling for all the residential and commercial properties [around 12,000 people] and has the potential to generate electricity using renewable energy source such as geothermal and/or solar. The development reduces energy consumption by between 40 and 50% (compared to the Model National Energy Code for Buildings). Energy savings occurs due to energy-efficient building envelopes, lighting, appliances and mechanical systems and through connection to a community energy system.

By involving the community in the visioning and planning phase, the main objectives were established for the redevelopment, including safe and pedestrian-friendly streets and parks, mixed land uses and building types.

The environmental responsibility led to the implementation of many LID (Low Impact Development) and landscape best practices such as maximizing tree canopy, absorptive planted surfaces, permeable pavers, green roofs (Fig.25), rainwater capture (Fig.26) and infiltration

[16] Note: Figure 21 and Figure 22 were removed but the rest of numbering is retained for consistency

galleries.

Also, Toronto Community Housing (TCH) has a long-term commitment to the project, as the owner and operator of the rental units. It pays for utilities as part of its operating costs, so operating cost savings make good business sense in the long term which is crucial in any municipal budget.

Figure 25. Extensive and intensive green roofs Source: CMHC

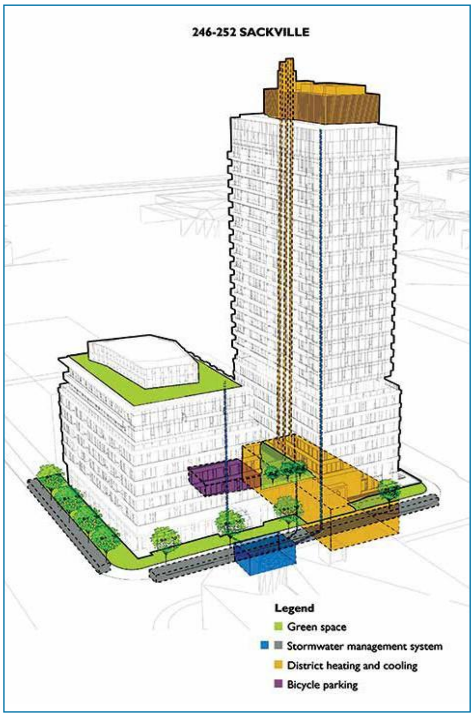


Figure 26. Rainwater capture from roof to underground infiltration tank. Source: CMHC

EQ TM Communities project – Station Pointe Greens (SPG) Edmonton, Alberta, Canada

Project-based on Passive House design principles will include if built as planned, apartments buildings from 6 to 18 storeys, and townhouses [Fig. 27] resulting in a transit-supportive development of 250 units per hectare. SPG will have all amenities on-site and a biological wastewater treatment facility [Fig. 28] to treat 100% of the wastewater to be re-used for toilets flushing and irrigation.
The design includes reduction of stormwater run-off through green roofs over 50% of the site and bio-retention cells. All those features combined with the light rail station and bus terminal can contribute to a very significant potential mitigation of the required infrastructure.

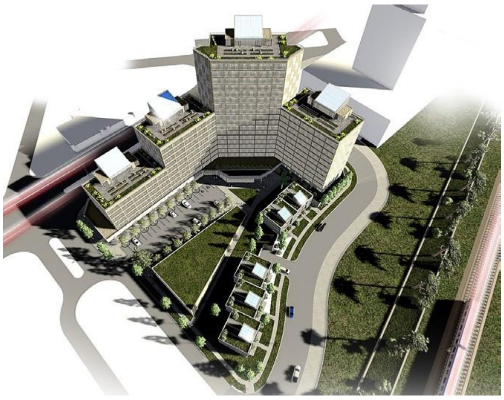


Figure 27. Aerial view. Source: Hartwig Architects

Figure 28. Wastewater treatment facility. Source: Hartwig Architects

Ampersand, Ottawa, Ontario

The Ampersand project is a mixed-use neighborhood development in the Chapman Mills Town Centre community in South Nepean, Ottawa [Fig. 29], [Fig.30], [Fig.31], [Fig.32]. The developer, the Minto Group, was also investigating the feasibility of achieving net-zero energy consumption within the development.

Figure 29. Ampersand Site Plan, courtesy of Minto Group Inc

Figure 30. Interior street. Source: Author

Figure 31. View of the park. Source: Author

Figure 32. NetZero building. Source: Author

Measures implemented in Ampersand that affect the infrastructure:

Energy: A 14 unit condominium apartment, targeting net-zero energy consumption and featuring photovoltaic panels, was completed in 2011. Other buildings include design features such as improved building envelopes and mechanical systems and energy-efficient appliances to reduce energy consumption. The feasibility of a community energy system powered by biomass and other renewable energy sources such as photovoltaics was investigated but later put on hold.

Water, Wastewater, and Stormwater: **S**tormwater run-off reduction from permeable pavements and green roofs and rainwater capture and treatment for irrigation.

Transportation: The site is adjacent to some daily destinations including grocery stores and restaurants and is a short walk to a rapid transit bus station and a proposed light rail transit station.

Natural Environment: A tree canopy covers 30% of the site providing areas for community and home-scale food growing.

Sustainable communities can be described as communities that support healthy eco-systems and healthy living conditions. Besides all the components necessary for daily life including an easily accessible, transit system; and pleasant public spaces they should be answering the need for understanding of the relationships between the diverse elements and functions of the built environment. They should also seek to capitalize on the interconnections between elements and systems (e.g., waste from one area providing fuel for another).

Designing at the neighborhood/community scale provides opportunities to integrate systems (such as water and energy systems) across multiple buildings and land uses. The infrastructure always benefits from such actions, and sustainable community projects in Canada and elsewhere demonstrate that certain principles apply universally, although with local, particular context and circumstances of the neighborhood/community.

Sustainable communities that are designed with these principles, can:

- significantly reduce energy and waste;
- reduce demand for urban resources;
- preserve ecosystems;
- increase health and quality of life.

- support healthy local economies; and
- lower short and long-term costs;

moreover, application of all those principles could lead to communities of our future.

The task of designing sustainable communities and neighborhoods places a considerable responsibility on architects and planners to be accountable not only to immediate clients and stakeholders but also to unseen stakeholders as well as future generations. With this responsibility, there also comes a tremendous opportunity to explore new expressions of urban form with total integration of all its components working together as a big system.

Other relevant examples

BedZED, London, UK

Beddington Zero [fossil] Energy Development or BedZED, is targeting low energy and renewable fuel, including biomass CHP and PVs, zero net carbon emissions, water conservation strategies, and biodiversity measures.

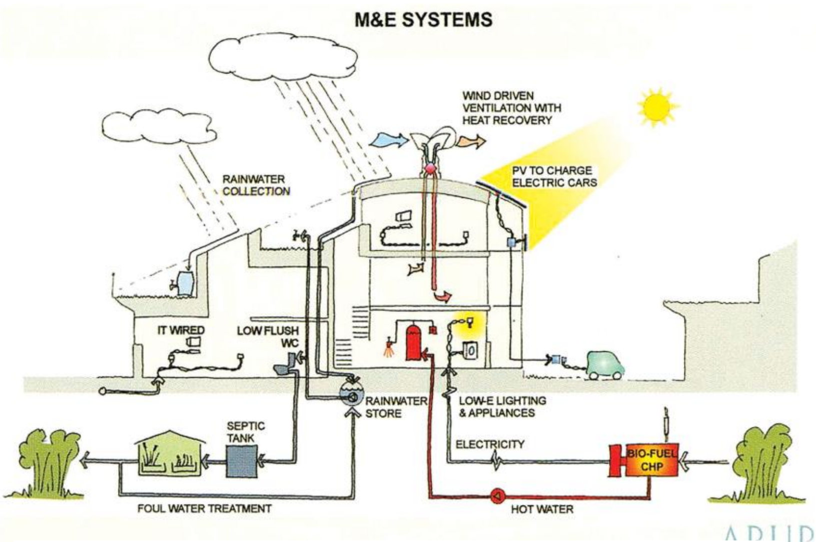


Figure 33. BedZED Systems. Source: Arup

BedZED combines both functions: capturing rainwater for reuse and processing blackwater on site to serve residential and office space. It produces its own energy in a CHP system, electricity with PVs integrated into the glazing. Green roofs and other sustainable strategies eliminate the need for municipal infrastructure [Fig. 33].

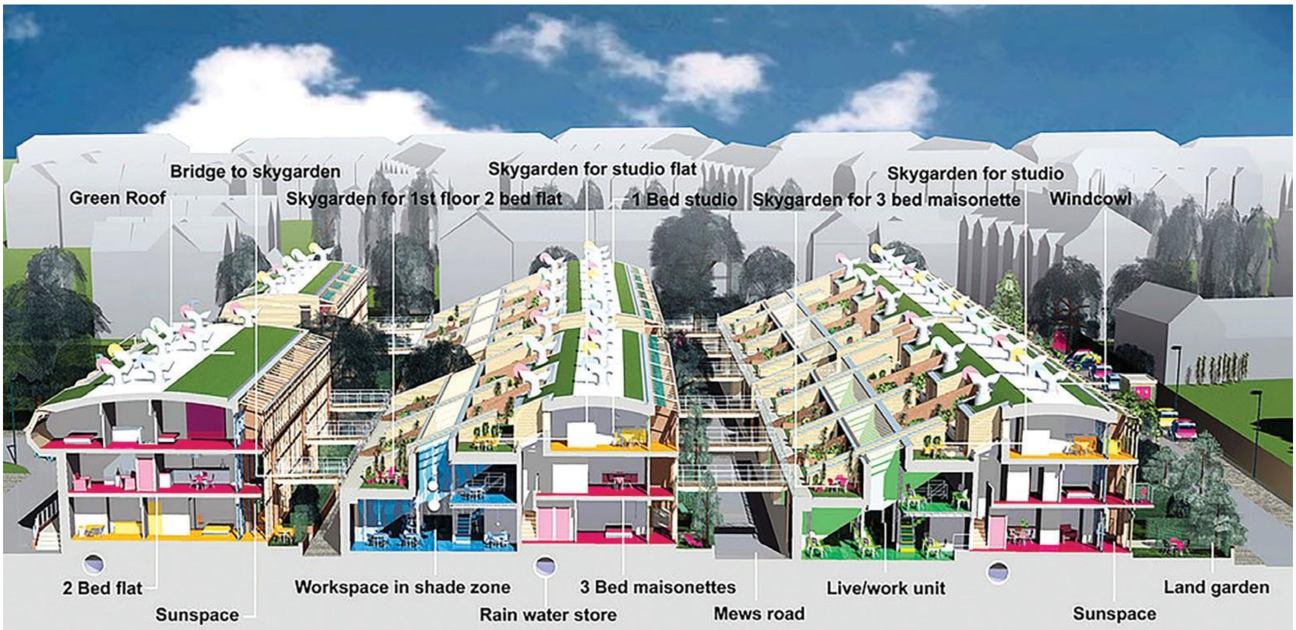


Figure 34. Sectional perspective. Source: zedfactory

It contributes to the transportation system using shared electric vehicles (powered by windows' PVs) and eliminating commuting by integrating workspaces nearby [Fig. 33], [Fig.34].

1.3. Retrofits

The renovation of the Willis Tower, Chicago, USA,
The entire project is a net contributor to Chicago's infrastructure capacity saving enough energy to supply one new hotel and adds capacity to the municipal grid[17].

Figure 35. The Willis Tower, Chicago [source: willistower.com

Replacement of its 16,000 windows, installation of new gas boilers using a fuel cell to generate electricity, solar panels to heat water for toilets, smart lighting, and control systems combined with the upgrade of elevators and escalators and conservation practices **led to a reduction of annual electricity consumption by 34 percent.** The building also saves 40% of the water each year, or the equivalent of 156,448 full bathtubs, by relying on low water-flow fixtures [Fig. 35]. An adjacent 50-storey energy-efficient hotel uses renewable energy systems to fulfill its energy demand. This new building uses less energy than that saved in the renovation of the Willis Tower. Thus the entire project is a net contributor to Chicago's infrastructure capacity. Existing buildings that were designed with a 50–100-year life expectancy [mainly institutional, hospitals, schools] usually are good candidates for retrofits such as re-glazing and installation of PVs or geothermal.

1.4. Other infrastructure-related issues

District heating systems

District heating systems, well known and used in Europe for over a century can be economically feasible when applied to high- density developments, especially with a low-cost energy source. If cogeneration is added, the waste heat from a district heating plant can also be used to

[17] https://traveldigg.com/willis-tower-the-chicagos-skyscraper [access: March 2017].

generate electrical power for the neighborhood; or heat from municipal sewage systems can be transferred back to the heating plant.

Greywater Reuse

Greywater reuse systems, used in new and existing buildings, capture water from laundry, showers, and sinks, then treat and reuse it for toilet flushing or irrigation. They conserve municipal potable water and can also reduce the wastewater infrastructure thus reducing water and sewage costs for owners and infrastructure costs to municipalities; however, some Canadian projects show that systems' costs can often outweigh the savings due mainly to the problems with training and maintenance, and cost of greywater treatment itself. Some provinces still do not allow the use of grey water in any systems under their jurisdiction due to the treatment concerns and liability.

2. Cost-Related Challenges & Design Considerations

Changes in the construction industry can be difficult to progress and usually are, but that positively, although slowly, changes. Some of those in the development community who believe, or rather "know," that the sustainable means too expensive or complicated, finally start to realize that there are no significant differences in average costs per unit area between sustainable buildings and conventional ones if looked at properly. However, from a developer's perspective, first costs are usually the most important factors, and long-term savings are rarely considered unless developer owns and operates such buildings.

The scale of design consideration is constrained by client interests and prerogatives and secondarily by the segmentation design responsibilities where infrastructure is the context rather than the scope. Designing for sustainability requires examining how a project can interact with the infrastructure. From a market perspective, strategies to reduce natural capital depletion (for example demand reduction, consumption efficiency, recovery) or build natural capital (for example water harvesting, renewable energy, artificial intelligence, horticulture[18], environmental improvements) must either provide acceptable return on investment or cost less. Life cycle costing needs to be comprehensive, accounting for all interactive effects and benefits/ savings [S. Moffat, G. Allen, 2002].

While there might be additional costs, they are typically not as high as assumed by the industry and based on the initial, not life-cycle, cost. This is primarily because long-term operational savings that are often found through measures documented in this dissertation (lower heating and cooling loads, lower water cost, revenue from construction waste, the sale of surplus energy, higher market values) can easily offset increased capital cost as shown in Table 3 below, especially with ever-rising energy prices, but also with the steadily dropping cost of renewable energy technologies.

[18] Horticulture is the science and art of growing plants (fruits, vegetables, flowers, and any other cultivar). It also includes plant conservation, landscape restoration, soil management, landscape and garden design, construction, and maintenance, and arboriculture. In contrast to agriculture, horticulture does not include large-scale crop production or animal husbandry. (Wikipedia, 2018)

Table 3. Cost of measures and related benefits

Capital and operating costs	Sustainable buildings reduce energy demand, can reduce capital and operating costs by optimizing equipment size (e.g., heating, ventilation or cooling systems, etc.). In warmer climates, for example, the use of "cool" roofs (high thermal mass, reflective surfaces, etc.) was found to reduce the capital costs required to provide air conditioning.
Density bonuses	Many municipalities offer density bonuses to developers providing certain amenities that benefit the community as a whole, and they are allowed to build more floor area thus deriving more income.
Building envelope	The properties of the building envelope (thermal, WWR, orientation, shading, form, glazing, etc) can reduce the costs associated with heating and cooling.
Renewable energy	Reduces the need for, or size of, fossil-fueled heating and cooling systems. Generating electrical energy from renewable sources can be a source of income, both regarding selling the power and through the potential sale of carbon credits.
Energy efficiency	Increasing energy efficiency and reducing GHG emissions could eventually allow developers to sell carbon credits or reduce operating costs to occupants (long-term savings)
Natural light and/or high-efficiency lighting	Designing properly formed, located and shaded buildings (to avoid overheating) reduces the electrical requirements for lighting. The capital cost of LED lighting can be high, but savings are immediate.
Transit-oriented development	Building near mass transit can substantially reduce the cost of additional parking and the required infrastructure in all forms
Active transportation amenities	Active transportation amenities, such as secure bicycle parking or better pedestrian areas, can reduce the amount of parking required to be built and maintained, and make streets safer for all users.
Green roofs	Green roofs reduce stormwater runoff (some municipalities require stormwater management in a building's design) and provide additional insulation, which can reduce heating, cooling and ducting requirements.
Xeriscaping	Planting native and/or drought-tolerant plants can reduce water consumption, landscaping infrastructure, and maintenance costs.
Rainwater capture	Reduces or eliminate the need and cost of potable water used for irrigation. Many municipalities charge more for water to cover higher treatment and delivery costs.
Incentive programs	Many federal and provincial governments, as well as many utilities, may offer incentive programs for green buildings or energy-efficiency retrofits.
Preferential financing	Preferred lines of credit or lower interest financing for sustainable buildings.
Preferential insurance rates	Some insurance companies now offer credits for firms that incorporate renewable energy into their buildings. Some are opposing the green roofs due to the potential installation problems.

There are also other, unexpectedly high costs. In the past decade, the insurance industry has been hit by mounting claims from extreme weather.

Urban flooding likely to worsen, say experts

Figure 36. The High River area of Hampton Hills is shown during the 2013 floods in Alberta. The cost of that flood helped focus on the extreme weather. Source: Jeff McIntosh/Canadian Press)

2013 is the year the Canadian government had to write a cheque to Alberta for $2.8 billion (*milliards in Europe*) for flood damage [Fig.36], to partly compensate for damage of more than $6 billion, while claims in southern Ontario from severe weather totalled $1.1 billion — a total of $3.4 billion in claims from catastrophic weather events for the year.

IV. **CONCLUSIONS**

1. Final Synthesis of Summaries and other related research[19]

Buildings, infrastructure, and the environment are inseparably linked. Energy, water, materials, and land are consumed in construction and operation processes while the environment impacts on living conditions. The infrastructure is part of everything built with the purpose of living, working, servicing, storing and producing that, simplifying, has to be connected to the source of water, energy and other required services. Those connecting networks can extend beyond the building, neighborhood, city, region and even a country. Every attempt to minimize such services - the infrastructure, is beneficial to all "stakeholders", including the environment that must be protected as much as possible.

The infrastructure's innards within buildings behave like ecosystems with their laws of nature, the equivalent of requirements and rights, while buildings, have theirs, being a vital part of a healthy infrastructure system. Such a system can be significantly improved, its reduction notwithstanding, by the implementation of many measures [Fig.37] including those in buildings designed and operated as both direct and indirect contributors while always taking into consideration their urban context. Such planning and building design require a thorough understanding of thermodynamic principles, physics, and design process itself, including at least, the principles of urban design.

In new communities, it is likely that elements of urban infrastructure systems will move much closer to-or inside-the buildings themselves, even in large urban centres, while in existing communities such integration may be both challenging and challenged.

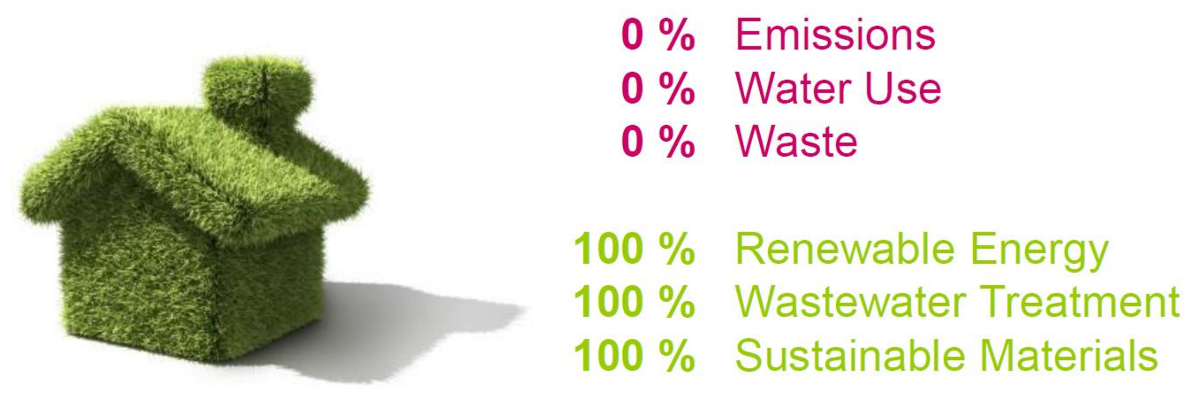


Figure 37. Plans. Source: Millenium, Vancouver

Buildings presented and analyzed through the conducted and published research constitute models for optimizing almost every aspect of the design that impacts the infrastructure in its urban, or suburban environments.

The conclusions from all modules are grouped and summarized and are presented here in a

19 after Mangone, 2015; Moffat, 2002; Neate, 2002; Larsson 2012; Salat et al., 2008; Stroemann, Sattrup, 2011; Gorgolewski et al; 2011, McKay, 2015; Rovers, 2006; Grammenos, 2009; Moffat, Allen, 2002; Pollard, 2016; Smith, 2010; Sood Joshi, Desormeaux, 2018; Kujawski, 2017 and other authors listed in bibliography

similar methodology with buildings first, then urban and communities issues impacting the infrastructure, and the final conclusions [refer to p.18]. The summaries synthesized in this section provide the answer to the research question about the possibilities of building contribution.

The first part is about the overall conclusions how buildings can be created, built and operated as well as monitored and evaluated not only by filling out the checklists or running computer programs, but also by asking users or occupants about their comfort level and the overall satisfaction. Only then the potential contribution can be acknowledged; however, in some cases, conclusions may seem trivial or simplistic when based on very simple to apply, but never used measures.

One of many principles of the green (building) design says that the green community will never be green by planting the hectares of photovoltaics and connecting them to a very inefficient, old (or new) cluster of buildings. Seemingly, it may become a Net Zero community, contributing to the infrastructure by decreasing or eliminating the energy demand entirely. Many reasons are proving that it is not right, and some are presented here as conclusions based on the author's research asking which buildings are real contributors themselves and which cannot be named as such.

Buildings that use less energy overall reduce their dependence on fossil fuels and cut GHG emissions that contribute to smog, air pollution and on a global scale, climate change. Such reductions have direct or indirect impacts on municipal infrastructure which, with its usual deficits, offers opportunities to buildings to lessen their impact on or add to the capacity of its systems if only architects and engineers apply the relevant design practices complementing them with the appropriate technologies but only after exhausting all other design measures. It means that following simple rules of the energy efficient design while choosing location, form, and good practice, the use of technologies can be either significantly mitigated or just avoided entirely.

The work presented in all modules proves that the improvements to the building design that impacts on the operation and levels of performance of the infrastructure are not only possible but are already happening to the point where buildings contribution is quite significant in several regions.

Such situations are possible when the buildings are:

- designed as a part of a community project with the efficient road and infrastructure patterns,
- net-zero or positive energy producers to minimize the need for new energy plants with their vast infrastructure, free up capacity within already existing energy systems and provide safe, secure and reliable sources of energy

moreover, they

- Include systems that treat and manage water, wastewater or stormwater, reducing or eliminating the need to be connected to municipal water systems,

- Use less energy, cut GHG emissions, air pollution and reduce their dependence on fossil fuels

The buildings built to the best standards will minimize the expansion of infrastructure to the minimum required and every step towards the efficiency of buildings contributes to the optimization of the infrastructure as well. Once buildings were identified with their potential roles, the analysis was performed of the neighborhood capacity and needs regarding energy, greywater, blackwater and heat including that from sewer and waste heat. The analysis has shown how to design buildings as the best contributors. For example, within the architectural features, improvements made to building envelope in both, new and existing buildings, could increase the energy performance significantly and minimize the life-cycle costs of buildings that include the operational energy savings.

The design and construction of all presented case study buildings were at their time significant achievements that set new standards for sustainable design, energy savings, building performance, and the comfort of residential and commercial occupants and employees in their workplaces. Buildings were analyzed in regards to the feasibility of upgrading their current performance and of reducing their needs in the future. They also represent the models for optimizing almost every aspect of the design that impacts the infrastructure in its urban, or suburban environments.

However, the fundamental idea is that without the understanding of a building as a system (of systems) it is impossible to proceed with the creative design and only the thorough understanding of the building's functions can directly link its actual performance to either innovation or corrections. The idea of the thesis is to close that knowledge gap and gather all "pieces of the puzzle" together.

Buildings that include water and wastewater treatment, and stormwater management systems, can reduce the impact on, or eliminate entirely the need to be connected to, municipal water systems. Buildings that use less energy overall cut GHG emissions that contribute to smog, air pollution, and climate change, and reduce their dependence on fossil fuels. Even recently constructed buildings may have potential there, especially those built only to the code requirements, or with mostly a profit in mind such as most of Toronto apartment buildings that require immediate remediation measures but when analyzed, they show the huge potential used, for instance, in Toronto Regent's Park and other small-scale developments.

Building size and form (on the housing example) play a significant role in the quantities of resources required in both the construction and operation of a home - as home size increases, so do both material and energy consumptions. Reducing material requirements through optimized building size and form can result in many different approaches to housing because the efficient larger home nevertheless consumes more than a similarly efficient smaller home, then for a family of a given size, a larger home uses more materials and energy to meet the same need. Similarly, on a scale of a community group of such homes will be drawing more energy impacting negatively on infrastructure.

The design process must balance efficiency in buildings through their size, form, function, technologies used and cost to result in an efficient, and marketable, product.

The detailed studies of buildings show that several architectural form parameters can significantly impact the annual heating and cooling load intensities. The most critical factor, relatively independent of the building geometry, was the combined building envelope performance considering wall insulation value, window U-value and window solar heat gain coefficient (SHGC), and the window-to-wall ratio (WWR). Floor plate geometry and building orientation typically have minor impacts on heating loads and slightly more significant impacts on cooling loads (being always within close range of one another).

The roofs that, as part of the envelope, can mitigate rainwater impact and heat losses and gains, can affect air quality, potential food production as well as the installation of solar collection/energy production systems.

Good envelope performance is essential, and it allows freedom in massing/orientation and the building geometry. One of the tactics is the use of a significant amount of insulation, high-performance windows (with location and orientation relevant glazing), thermal breaks, and the airtight construction. However, the amount of embodied energy in massive amounts of certain types of insulation and the environmental impact of materials can bypass most of the energy savings from the increased performance.

In determining the environmental impact of the buildings, several studies show that it is essential to take into account the perspective of buildings' life cycle through the Life Cycle Assessment (LCA) that depends on used materials, the impact of the design itself, construction process, operation and maintenance during the period of use and the demolition. Such an assessment can provide useful insights into both the durability[20] and resilience[21] of all relevant elements. The development of both the building and the infrastructure is influenced by the balance of benefits and losses and requires a detailed study with all considered conditions.

The use of the low impact materials can significantly reduce the environmental impact of buildings. Durable materials and buildings constructed with them can provide a better outcome and allow optimization of the resources required to maintain and repair buildings, such as energy with its emissions, waste, and transportation therefore directly impacting the size and quality of the infrastructure.

The results from the study on high-performance building designs indicated that they were considerably more materially, technologically and hence energy-intensive if compared to the conventional building code baselines. However, the operating energy demand of such designs (for example a NetZero home) was found to be between three to five times lower than their comparable versions.

[20] the selection and integration of durable, low- maintenance building elements, equipment and systems that greatly reduce potential future risks, in the short and long term.

[21] future adaptability or "future proofing"—the selection of resilient building systems that can be adapted over the long term with changing demands on thebuilding including changes in energy sources, climate change and severe weather events.

Design of more durable building reduces the exposure of the building envelope to moisture, the primary deterioration factor, through improved drainage around foundation walls, improved air tightness of the envelope and better weather protection of the facade. Use of higher quality materials can significantly improve the durability of the building and its infrastructure. Designs must also take into account the ease of maintenance and repair of the critical components in the building ensuring that a failure of any component of the building does not cause long-lasting or permanent damage. The typical financial problem is that shorter payback periods valuing 'the quicker, the better' (not necessarily, the cheaper) usually disregards what the best for occupants and the environment is.

Part of the research on the building performance is closely related to its occupants. The initial Post Occupancy Evaluation (POE) survey determines the extent of their satisfaction and monitoring of equipment and systems gather the data through all seasons, preparing for further analysis and actions if needed. The findings from POEs can improve the operation of existing buildings, and the design, construction, and operation of new ones. Such improvements will have an impact on the level of the infrastructure use – existing and planned. Relations to the infrastructure while evaluating building performance are apparent, and the POE is an excellent opportunity to improve it.

The building contribution depends on the various strategies and techniques but also on the specific context – the immediate neighborhood and then the urban pattern around it. The poor solar planning, site related, is a primary issue impacting the integration of solar thermal and PV.

Another essential part is related to water and its infrastructure network. One of the best ways to reduce the demand for potable water and the production of wastewater is by improving the efficiency of water use that can come as the result of changes in hardware and others in changes to habits as well as to use appropriate water quality for intended purposes. Outdoor residential water use can be significantly reduced by employing alternative landscape designs – like Xeriscaping requiring the minimum amount of maintenance and irrigation. Use of permeable hard surfaces designed for infiltration is essential for enabling trees and other plants to get the water they need and for reducing stress on municipal stormwater systems.

Urban" means a planning pattern, characteristic of the highly populated area with infrastructure; however, it may be applied from a specifically oriented building to a block, neighborhood, community, district, city, and agglomeration. Urban geometry is an essential factor in energy-optimized architecture as energy savings from an urban design are very long-term while also reducing the need for costly technologies.

Hybrid infrastructure is defined as systems that are integrated within buildings and landscapes that also provide non-infrastructure uses, and they can improve the economic performance of municipal infrastructure. Such infrastructure can be incorporated into buildings in a manner that allows the building systems, occupants, and owners to benefit from the physical system components, spaces, surfaces, materials, and process by-products, such as waste heat. The integration of municipal infrastructure into buildings and landscapes can generate diverse economic opportunities for local communities, building owners, and occupants.

With the advances in renewable energy technologies such as photovoltaics (PVs), geothermal and in heating and cooling systems, combined heat and power (CHP), the viability of local energy production has improved significantly. Local and individual production can also reduce the peak energy demand and stresses it generates within a community energy system.

When individual buildings can take on the role of producers in sufficient numbers, then retrofitting and expansion of existing grids is avoided - the main reason behind a strong push from big utilities for efficiency and use of renewable energy leading to stable or decreased levels of energy demand despite the constant growth of the economy. Similarly, many communities became stronger and more resilient by implementing decentralized systems in which the entire neighborhoods could remain functional during and after an event, be it climatic, weather-related or a natural disaster.

The study relevant to the impacts of housing on a scale of a country showed that land use patterns could be categorized regarding amount, density, mix and location of housing, and these elements, directly and indirectly, affect infrastructure requirements, transportation mode choice and the building stock which, in turn, impacts energy and other resource use. Regardless of dwelling type, neighborhood type contributes to the transportation pattern of residents thus to road infrastructure. When considering dwelling types, single detached houses would have the highest environmental impacts, and among neighborhood types, outer suburbs would have the highest environmental outputs per dwelling. Those impacts will be mirrored infrastructure wise, thus the consideration should be given to these aspects of housing developments.

It is possible to incorporate Energy Elasticity & Resiliency (not just Fuel Switching) by cooperation, conservation and sharing at the community level, for example, the surplus of heating and cooling power and power itself that can be available from nearby commercial / municipal facilities (supporting the idea of Synergy Zones). Stormwater from large paved sites and roof areas has severe impacts on local ecosystems (oil accumulation, erosion of natural water-courses and flooding of treatment facilities) and municipal systems (storm sewers are sized for peak periods) and proper stormwater management can reduce stress on the sewer system. Grey water is still of concern even after all measures of water saving due to a need of treatment and separation of it in plumbing systems.

Water touches all aspects of life, and thus should touch all aspects of design. The objective of the Water-Sensitive Urban Design (WSUD) is to integrate urban design with natural ecological processes and add value to the development of scale with its water infrastructure which, in other more scientific words becomes the following: ***to maintain or replicate the pre-development water cycle through the use of design techniques to create a functionally equivalent hydrological landscape.***

In the design of high-performance building, sustainable materials are specified from local renewable resources; construction waste is reduced and well-managed, construction impact on the surrounding area and watershed is reduced through reduced erosion and durability of building components is emphasized. Using efficient water and wastewater systems, site design and landscaping provide for on-site rainwater use, stormwater retention and reduced infrastructure costs.

Despite the decrease in water consumption, total water use will still increase due to the growth of the entire residential sector. The water usage has significant dimensions: the supply and the depletion of the water resource and the effects on water quality, partially addressed by urban water treatment infrastructure. Other environmental impacts of developments of scale are, for example, fundamental changes to the water cycle in urban areas that would occur unless management measures are taken, such as allowing groundwater recharge, especially when large fields of boreholes for geothermal energy are in continuous use over several years. Sometimes it may lead to the unforeseen (by the user) resource, such as underground aquifers, depletion, and closure of energy plant.

Various positive approaches can mitigate the thermal deterioration of urban environments. Conserving existing green spaces in urban settings, using more appropriate materials in the built environment, opting for designs that address both the issues and their impacts, reducing impermeable surfaces and developing a better public transit policy should reduce the presence of urban heat islands and affect the infrastructure directly.

The impact of urban heat islands can cause temperature raising in cities by 2 degrees C stronger than in other, non-highly urbanized areas. That means a much higher demand for air conditioning, thus energy, and general problems such as, for example, lower productivity and high vacancy rates resulting from the lack of comfort satisfaction but affecting the operations and stability of the infrastructure systems. The efficient approach with early adoption of simultaneously implemented various mitigation measures produce benefits such as lower surface and felt temperatures, reduced mortality, better quality of life, less smog, smaller temperature variances, the longer useful life of materials, energy savings, higher property values and fewer floods (from climate changes caused also by the effects of heat islands).

One of the most fundamental questions in urban planning and building regulations is how to secure universal access to sun, light and fresh air, all affecting the energy use of buildings and related infrastructure. Urban context, an essential factor in the building energy demand, is often overlooked in favor of individual building performance. Unobstructed volumes use two times less energy than the non-passive volume and an efficient building in an efficient urban fabric can consume even four times less energy than a non-efficient one.

The most important factors besides the local climate, affecting the amount of available daylight are the ratio between the building heights and the street width between buildings, a reflectance of the exterior building materials and ground surfaces, and the area of windows. The overall energy consumption of buildings depends in part on available daylight to provide the required level of light, thus directly affects the infrastructure loads.

The research and executed projects presented in the dissertation used specific guidelines that not always were scientifically defined but still achieved their goals on a smaller scale of a building or home and not of a neighborhood or community where very local conditions determined by the urban pattern, appear. The urban canyon belongs to these conditions. Its name - urban canyon- has been used in urban climatology describing, in geometric terms, the height to width ratio of the space between adjacent buildings. The link between urban density and building energy use is an intricate balance between climatic and spatial factors, material and urban use patterns with buildings that constitute them.

Optimization of energy in the building and urban designs in ever-growing cities requires an understanding of all interrelations between them, and the conclusions strongly support the thesis that buildings, if adequately designed within equally well thought off urban context, are major contributors to the infrastructure.

Local streets create main road network within a community and become a determinant of the designer's creative input in buildings and infrastructure in any urban development. The outcomes of other presented studies only confirm such relations as, for example, the design of permeable areas that decrease stormwater systems, contributes positively to the urban heat island effect by lessening the energy demand for cooling and increases urban comfort. The connection of permeability of the ground surfaces around the buildings is very much related to the designed building and its operations, and thus it is one of the elements of a contribution to the infrastructure. That also applies to a partial local road network that can be built with permeable pavers while being resistant to heavy traffic including required fire trucks.

Well-designed streets can also mitigate traffic and enable active transportation (walking, cycling), which can reduce the energy required for transportation and related GHG emissions. Even minor adjustments to street patterns can create opportunities to build higher density developments and reduce the impacts on municipal infrastructure while raising the viability of shared energy systems.

The thesis is also supported through the subjects related to transportation where impacts of buildings are not only about indirect transportation emissions but from the built infrastructure such as highways, feeder roads, streets. All of them must be constructed and maintained in a long-term with other services such as water drainage, stormwater management, electrical services - lighting, traffic light, overall controls. The infrastructure must survive winter, and that means considerable expenses in snow clearing and extensive repairs every year to the majority of roads due to “freeze and thaw” cycles.

The potential role of small urban areas offers possibilities to improve the aggregate performance of buildings in concepts, such as Synergy Zone, a model that builds on the form of synergistic performance in energy, emissions and water and other less critical issues. They include the use of renewable DC power with minimized conversion losses, the distribution of thermal energy from buildings with a surplus to those with deficits, and similarly more efficient use of surplus greywater [Fig. 32][Fig.33].

The performance synergies can be achieved within mixed-use buildings in urban settings, such as different schedules within each occupancy for peak electrical or space heating or cooling demand. It is especially valid where the area of a cluster is small enough (economy of scale) to allow active thermal transfer between buildings also allowing direct use of DC power to buildings in the cluster.

Specific technical infrastructure features can be designed to improve occupants well-being, such as, for example, designing part of a neighborhood rainwater storage system as a falling water feature with sounds and light - both stress and anxiety relievers. Water tanks can also function as thermal mass and shade for a building and, depending on a context, can substantially improve the thermal comfort of building space, optimize occupant's satisfaction resulting in a much more cautious approach to the use of energy, thus positively affecting infrastructure's size and usage.

For the functioning of any modern urban area, critical "soft" infrastructure is necessary, such as hospitals, public transport, food supplies, water and sewage facilities which should operate at a basic level in all extreme or emergency conditions. The Synergy Zones concept can meet such demand; the hybrid infrastructure shows that it can be resilient, redundant and modular providing the same, similar, or backup functions. Using those concepts can result in a significant improvement of the situation after the climatic or other unexpected events besides a regular function of the energy provider be it thermal or electrical one.

Part of a green infrastructure system consists of Low-Impact Development (LID) practices such as stormwater management, stormwater runoff volumes, green roofs, permeable pavements, soakaways. Landscape best practices include other infrastructure related measures like design that minimizes the need for irrigation- up to the elimination of the water pipe network, maximization of tree canopy- shading leading to energy savings, pedestrian-oriented routes, streetscapes and open spaces – minimization of car traffic.

Landscaping practices have also elements related to urban farming on a small, not industrial, scale. Design principles for urban agriculture provide a framework and context to guide more detailed design strategies aiming to create an infrastructure that celebrates food production, preparation, and consumption and leads to diverse, productive landscapes.

The potential contribution of designs linking spaces like riverbanks, median strips, public parks, schoolyards and boulevards with the urban agriculture of buildings and communities - the transformation of "lost," or just underused, urban space containing buildings could have a huge impact on the infrastructure. When features, such as farmer's markets, greenhouses, edible landscapes, living walls, permeable pavings, green roofs, and community gardens can be incorporated into a design, it may change the basics directing any urban design.

Urban farming can become the remedy for increasing food demand, a solution to the increasing urban areas with no green spaces and a relief in the age of global warming. Buildings in such cases can provide direct benefits such as, for example, an improved thermal performance due to green roofs and green walls acting as insulation buffers, so acting as an infrastructure contributor. Furthermore, the major advantage of rooftop gardens is that they cut on the transportation energy as they are not (generally) used on a commercial scale serving only occupants of the building.

In relation to the urban issues, the point in the reduction of car dependency is that the scale of departure from the car depends on the offered alternative and the level of spatial planning. There are cities, even with public transit, where cars are a necessity: sidewalks are in poor condition, use of a bike is not possible because of mud, and the public transit is not safe, either. However, the rebuilt and renovated streets with the increased ratio of sidewalks and bike paths become the very crowded liveable area with much fewer cars. As it is proven in other presented studies, such situation can come from urban planning that includes by default sustainable buildings and the architectural approach is, or can be by default, holistic, thus very different from the conventional one. As mentioned earlier, the planning principles are subordinated to other sustainability rules and involve urban patterns with buildings that can already positively contribute having impacts on the embodied energy needed for construction of the optimized road network and the infrastructure, and on the total energy consumption also depending on a new landscape design that provides shading and stormwater (pumping) capacity.

The engagement of the residents in operation and maintenance of their building may also play a key role in the overall energy use and savings. An additional aspect is reserved to human factors such as level of occupant's satisfaction which, if acceptable, limits lost energy in vacancies and unused urban spaces contributing indirectly to the more stable infrastructure loads.

Occupants, with their behavior impacting the building performance, create a valuable contribution to the infrastructure underlining the fact that they determine the outcome of most energy efficiency measures. Another aspect is their financial consideration. The use of data representing internal rates of return -IRRs and simple paybacks in materials and technologies shows the need for precise economic analysis and performance modeling in estimating these values, as well as the importance of factors such as house type, location, fuel type, levels of insulation and air change rates. Without this approach, even the "green" consumer can be easily misled by simple statements, and the predicted performance of buildings will look good only on the computer screen.

Integrated planning on a scale of sustainable neighborhood or community can provide significant benefits including costs. Through a combination of innovative design, and state-of-the-art equipment, the optimized design can significantly cut the operating energy consumption, and with the use of "smart" technologies, it can reduce peak demand by shifting some electricity demand from high-use to low-use periods. Analyses with the optimization of buildings and the area around can create opportunities for energy and water integration as well as the use of renewable energy and waste within the community systems. District-scale development planning can also facilitate pedestrian-friendly alternatives such as walking and cycling routes as well as better developed public transportation.

A sustainable community is a community that supports healthy ecosystems and healthy living conditions and offers a variety of types and sizes of buildings, social, educational and cultural facilities. It should include a full diversity of land use, commercial and service opportunities along with public space, and easily accessible, connected and affordable communication systems.

At the scale of a community, it is necessary to include social aspects that are reflected by the satisfaction of translation into a better understanding of the environment that leads inhabitants to improved, healthier life. Such an approach goes than to the infrastructure as a direct impact of buildings in which people save energy and water and care about waste while biking to their workplace.

Designing such a community requires an interdisciplinary design team in an integrated design process that involves an extensive community and stakeholder engagement with a thorough understanding of the relationships between the diverse elements and functions of the built environment. The design provides opportunities to integrate systems (such as water and energy systems) across multiple buildings and land uses. The infrastructure always benefits from such actions, and sustainable community projects in Canada and elsewhere demonstrate that specific principles apply universally, although they are, or should be, interpreted locally to suit the particular context of the neighborhood or community. Communities designed with these principles can, in relation to the impacts on infrastructure significantly reduce energy and waste, reduce demand for urban resources and can preserve ecosystems.

One of the presented examples proves the thesis as measures applied to Angus Technopole Locoshop in Montreal -the first industrial redevelopment with a green building approach in Canada- directly affected the entire site and its infrastructure. Main criteria included the development of a building concept within its economic, historical and social contexts, at a competitive cost. With the pressure of the community, all objectives were achieved including the creation of the energy-efficient green building, water use and treatment, recycling and reuse of most materials, saving on resources, and indirectly on production and transportation of materials. Most of these aspects directly influence the capacity and operations of the infrastructure.

Many municipalities are finding increasingly difficult and expensive to keep up with the growing requirements for fresh water and sewage treatment facilities often not understanding that each measure that reduces water demand, also reduces infrastructure needs.

The design charrette processes for the Beaver Barracks in Ottawa, the Rosemont and Bois Ellen developments in Montreal, all described in their related modules, are other examples of an integrated process demonstrating the benefits of diverse stakeholders engagement in the concept design. The charrette helped the owners identify technologies and practices improving the overall sustainability as almost all aspects of the building design, as well as the neighborhood itself, play a role in the contribution to the required and operating infrastructure.

The process itself ensured that every feature was well studied, and the results show that a direct energy contribution came from the proposed and built community geothermal systems (in both Beaver Barracks and Rosemont) that provides all buildings on the site with space heating, space cooling, and domestic hot water. Other contributions derive from the significant reduction of both energy and water consumption and through the management such as the green roof contributing to the stormwater services and indirectly to the transportation emissions cut due to the vegetables growing there and the possibility of the rest. Very often such measures are unnoticed or just are taken for granted while, for example, the water saving reduces the size of plumbing systems, or energy conservation reduces the mechanical system's size. However, all measures still depend on the sound design and the will of designers to pursue the goals. In the urban context, the site plan determines how the building interacts with the surrounding neighborhood and environment. Careful site planning can contribute to the efficiency of the individual building (including optimization of its location, orientation, and landscaping), minimize the impact of it on the surrounding environment including its infrastructure and contribute to a 'healthy' social environment.

The use of solar power in all aspects of it became a staple within the design circles of progressive architecture. With clear guidelines for *What and How* to do it, the architects can quickly follow the path, making sure that their efforts also go towards the adjacent, and essential, infrastructure.

There are many existing tools, a lot of data and experienced professionals to learn from and making buildings as contributors to a community infrastructure can be beneficial to everybody from the owner, through the users/occupant to the greater community. With typical municipal infrastructure shortfalls, buildings can play a more significant role in lessening their impact on or adding to the capacity of an already strained infrastructure system.

Figure 38. North Vancouver - Identification of industrial buildings with excess energy or waste. Refer to p.54. Source: CMHC

Figure 39. Solar Thermal installations, Amersfoort, Netherland. Source: W.Kujawski

It is crucial to describe in more details the process of design itself that cannot be neglected in any project of significant size (cost wise as well) - an Integrated Design Process[22] (IDP). The use of an IDP from the moment of the project inception to the commissioning of a net zero or net-positive energy building will contribute, in turn, through its extreme energy and water efficiency goals, to the reduction or elimination of the standard infrastructure

The design process should reflect ecological and holistic principles such as:

- Networks of interactions
- Community consensus
- Creative evolution rather than imposing solutions

22 an organizational model or process that can and should be adapted to the unique circumstances of each project. It is based on a close cooperation of all involved parties from the very early stage of design to the commissioning/operational stage.

.A primary requirement of the IDP is to optimize the technical side of the design through the correct choice of form, function, structure and construction products and by following the principle "as little technology as possible, just as much as needed," to substantially reduce construction cost and operation and maintenance (O&M) costs that are all related to energy and water use in all forms, thus to infrastructure.

Designers and design teams need to think and participate holistically- sharing the inventions. However, the question to be answered as soon as the objectives and impacts are clear: how do such options affect societal benefit, client investment criteria, the robustness of the technology, cost of maintenance, ease of adoption, compatibility with site conditions and other factors?

Practically every home can benefit from the contribution to its infrastructure in all forms, but the most significant objectives may be achieved on larger scales starting from a neighborhood. The impact of the contribution of a single small building can be seen and felt mainly by the owner. However, if there are many such homes, their cumulative impacts may become very significant.

As shown in the examples, net zero and net positive buildings and neighborhoods are becoming more and more commonplace—either as new construction or retrofits of existing buildings and building developments/ neighborhoods. Relatively easy construction of Net Zero Ready buildings (with all services ready for the installation of PVs or solar thermal systems) that are resilient and with little or no special maintenance itself will have a huge impact, if built in numbers, on every aspect of the surrounding infrastructure including energy, potable, grey and black water, stormwater and waste.

A different situation arises with large and tall buildings which may become producers of their own energy and water through the application of appropriate design principles. Good examples are the Willis Tower in Chicago and Conde Nast building in New York

Infrastructure should be seen from the life cycle perspective not only because it sometimes stays much longer than the served buildings, but also because it is essential for the building and its neighborhood to function correctly. A building, to stay in excellent condition, should be constructed following the principles of resilience. However, it will not help if the built environment, including buildings, suddenly require much bigger capacity or have spikes in demand exceeding any safety measures so both should be carefully evaluated. One of the measures is to assess the maintenance of buildings that weighs heavily on the size and operation of infrastructure and consider potential improvements or optimization through the appropriate materials, equipment and procedures that also belong to the topic of life cycle impact.

Designs and construction practices allowing for long useful lifetimes represent efficiency in resource use. The principle belongs to both the buildings and the infrastructure interchangeably affecting the direct energy consumption and the embodied energy related to the used materials in cradle-to-gate (extraction to operation) principle. It is necessary to understand deeply the implications of material choices to ensure that operating energy objectives do not come at the expense of increased embodied energy use and environmental impacts.

The research findings illustrate the benefits and trade-offs associated with the pursuit of high-performance design, namely, low operating energy consumption versus increased material usage and higher related embodied energy. The presented characteristics support the thesis: the use of specific materials in buildings, even if environmentally wrong, can contribute to the decrease of energy consumption and, as proven, is a leading factor contributing to the size of the required infrastructure in both utilities and transportation services area.

However, it is imperative to look at all aspects of such a contribution. High performance and resilient buildings and by default types of the neighborhood (always related to buildings) with their equally resilient infrastructure may stay in shape against the adverse weather or other events but can also contribute very quickly to the damage of the environment, and that is where and when the balance must be found. Another simplified example, besides the insulation, is the production of aluminum windows or photovoltaic cells. The total embodied energy (consumed by the extraction and manufacturing) of both well exceeds any energy savings. However, the equation does not implicate the location and the constraints due to local conditions such as the insufficient capacity of existing infrastructure or a need for the high-performance building due to the comfort requirements.

The development of the assessment tools allows easy identification of local factors and the insertion of region-specific values for benchmarks, weightings, and standards adding a possibility of seeing immediately the implications of measures considered in a design. Combination of a building assessment's results of a predicted performance with a tool for infrastructure costing gives a municipality unlimited possibility for the evaluation of considered options with either established benchmarks for the building or the infrastructure.

The author's research established background information for studies that, when combined with high-quality energy simulations, can give the best results within the predicted performance of buildings. Such data is then used to establish the infrastructure capacity which, by default, is then optimized on a scale of a neighborhood or a community with all measures analyzed through the building design process.

The problem is that the proper regulatory verification still does not exist and the performance claims on anything green or high performance have to be supported by reliable analytical processes helping, in the end, making right choices. The researchers and professionals also have to remember that the results are as precise as the input data which is especially important with the predicted and not actual, performance when "anything" can be entered.

Such data entry is also relevant to the thesis and the potential of using correctly structured or wrong data. That can be applied to every aspect of life analyzed today with the use of the Big Data - sourced from sensors, satellites, digital pictures and videos, banking records, cell phones, GPS signals, climate data, wireless networks; every bit of exchanged data in daily lives is part of analytics. It also applies to the aspect of buildings and their operations affecting the infrastructure from the monitoring controls through the operation to management on all levels. Control goes to continuous performance assessment of the building, market conditions, operational statistics- all to improve the overall performance of the built environment.

Simulations create the opportunity to evaluate many solutions and choose the option that best meets the requirements or goals. They are the indispensable tool in determining the contributory side of buildings towards the infrastructure and can also evaluate it from many perspectives vital for either extension or reduction and analysis of its behavior under given or required circumstances. Simulations scenarios developed through the design development process should be based on an integrated design process because only then all benefits can be seen and used.

While looking at world examples of the low -impact housing several conclusions seem to be very relevant to the building contribution to infrastructure, such as the poor solar planning with the insulation "replacement," integration of solar thermal and PV into the building envelope resulting in a better quality/cost ratio. The overall primary conclusion from this "worldwide" research is that there is a need for benchmarks, references, clearer guidelines and goals, as well as criteria for overall green performance ratings as it may be difficult to assess with confidence and consistency.

The assessment of the potential of renewable energy systems in buildings is crucial for the long-term urban planning and evaluations of needs meaning also the opportunities impacting on the existing or future infrastructure. The research concluded that without substantial reduction in the overall energy demand, in both electricity and thermal, the solar technologies may not meet the energy demand in the residential sector and the incorporation of all measures is recommended.

Thus, such a conclusion supports the thesis that the buildings can supply the energy complementing the existing grid; however, the total dependence on renewable sources would not be possible in the near future unless using all measures available on a global scale including substantial cuts to the demand. The level of research was beyond a single building and its design; however, its usefulness was unquestionable, as it merely shows what could be viable in any particular location in Canada and the research, as such, may be used by the policymakers on a national scale in any location in similar climatic zones and economy.

The architects can quickly follow the solar path if they have clear guidelines, making sure that their efforts also go towards the adjacent, always indispensable and essential, infrastructure. If significant reductions in energy demand are not possible through increased insulation levels and significant mitigation of air leakage, they may happen with configurations of zero energy/emission mechanical systems (high-efficiency geothermal, solar thermal and PV). However, such ideas are in apparent contradiction with the elementary statement that "first the best design and only then technologies, if needed at all."

Other features related to infrastructure such as green roofs, permeable sites, minimized building footprint, maintained trees, and restoration of degraded areas are all "a must" in sustainable design. Such design should minimize stormwater system and increase the amount of permeable surface on the site.

"Intelligence" of the buildings is also a factor not to be neglected while more and more buildings and the entire neighborhoods are relying on the "smart controls" with the ultimate goal of health and comfort of the user and the presumed protection of the environment through the building high-performance goals. The intelligence allows managing the operations of the built environment such as buildings and the infrastructure within their urban model requiring the construction of the roads with their related services.

A projection of the climatic or catastrophic events and their effects on the built environment can serve as an example, where the most improbable disaster scenarios are simulated on models corresponding to real buildings and their surroundings by default also related to the infrastructure. The disasters like Sandy, Katrina and similar calamities can be simulated as the case studies.

Simulations are also crucial in cost projections where different scenarios are analyzed through all phases of the IDP during which a life cycle cost analysis has to be completed. The components of such analysis should be reasonable and realistic, and the estimations can be supported with the appropriate simulations and documentation. Cost-effectively implemented features of an environmentally conscious design of all types of buildings, can be seen together with the improved infrastructure aspects, such as energy and water efficiency, waste treatment through to transportation ease and renewable energy on site.

Infrastructure matters because it represents the significant capital outlay for the developer and an essential accounting element in pricing, after land. […] to be competitive infrastructure costs have to be equal to or lower than what conventionally has been achieved in previous developments or by the industry at large [Grammenos, 2009].

Because budgeting of any project is crucial, there are many programs to facilitate it, and their main characteristic is that they allow considering options. Life cycle costing (LCC) helps local governments look beyond initial capital costs and can assess infrastructure strategically over its entire life significantly strengthening fiscal performance. The Life Cycle Costing Tool for Community Infrastructure Planning can help owners and developers estimate the approximate costs of development and to compare alternative development- different options for types of infrastructure[23]. Reduction of potential costs of a road network can switch funding towards building performance improvements impacting on infrastructure.

Various initiatives and programs offer to architects and community designers the opportunities, by managing loads, to relieve the infrastructure during heat waves or cold snaps, and to avoid having to pay peak rate energy costs. Such situations also trigger utility outages or spikes that can be avoided using renewable energy and backup power capabilities that appear suitable for both large cities and smaller communities.

The infrastructure is built, maintained and operated in an unbreakable relationship to the

[23] It is available at http://www.cscd.gov.bc.ca/lgd/greencommunities/sustainable_development.htm Accessed in March 2018

buildings, and they play an integral part in it not only by collecting but also by contributing to it with practically every aspect of the design and operation.

“

2. Final Conclusions

The thesis that buildings are contributing to urban infrastructure has been proven. They are not only active collectors of energy and water but also active contributors - the critical aspect of the thesis. The answer to the research question[24] can be summarized in essential points:

- Specific, described design measures should be applied to high-performance buildings - energy producers, such as to optimize the building energy efficiency, hence the operation of the infrastructure, to free up capacity within their energy systems, including renewable sources, and to provide dependable sources of energy shared between the buildings;
- Both urban morphology and urban geometry aspects should be considered in building design;
- The design should also include the systems that treat and manage water, wastewater and stormwater while reducing or eliminating the connections to municipal systems, and counteract climate changes and the infrastructure overloads by protecting the watersheds appropriately.

  The improvements to the infrastructure itself using the solutions mentioned in the dissertation can also bind three sustainability pillars to be responsible for "urbanization" consisting of economic activity, socio-cultural exchange, energy demand, required supplies of raw materials, waste management and environmental pollution.

The vital factor is to achieve and maintain a positive balance between the elements such as:

- (un)controlled development of suburbs,
- problems with energy supply and rising prices (potentially resulting in the energy exclusion, when people face a choice between food or energy),
- water problems - supply, discharge, stormwater management
- environmental pollution,

The buildings designed with the principles of the urban morphology and geometry, and built to the best standards, will minimize the infrastructure to the minimum required while helping optimize it and every step towards the energy and water efficiencies of buildings within their urban context contributes directly and indirectly to the infrastructure.

„We transform ecosystems to sustain ourselves. This is what we do and have always done. Our planet's human carrying capacity emerges from the capabilities of our social systems and our technologies more than from any environmental limits. Our growth will be supported as long as we continue to invest in infrastructure, anti-poverty, and food security."[25]

Figure 40. Bahrain World Trade Centre. Source: iiSBE, http://www.iisbe.org/

[24] Can modern buildings, considering all their technical design aspects, but including also occupants' comfort, play an essential role in the dynamics of urban infrastructure, not only by quantitatively contributing to its performance but also constituting a conscious part of the designers' planning of new synergies between buildings and their environment?

[25] Erle Ellis, University of Maryland, 2013

BIBLIOGRAPHY

List of publications and web references used over years of work within the subject

Publications and web references

1. W.Kujawski, *Optymalizacja kosztów inwestycji w świetle zrównoważonego rozwoju*, prezentacja na VI międzynarodowej konferencji „Inteligentny Budynek" we Wrocławiu w czerwcu 2001
2. W. Kujawski, Green Building Conference, Ottawa, 2010, *How retrofitting existing buildings can contribute to the urban infrastructure*
3. W.Kujawski, *Conde Nast 4 Times Square Advanced Buildings Newsletter*, nr 25/2000
4. W.Kujawski, *Czy drapacz chmur może być ekologioczny ?,* Architektura-Murator, 10/2000
5. Kujawski W., Pollard D., *some case studies*, Grammenos F. – Fused Grid Boddy S.– writer Contracted by CMHC. Buildings as Infrastructure Contributors
6. W.Kujawski, *Symulacje – niezbędna pomoc dla projektanta,* Architektura-Murator, 12/2000Natural Resources Canada - Buildings Group, http://buildingsgroup.net
7. S. Nair, S. Patel, *Urban Farming, students of Eco Design*, Algonquin College, 2018, W.Kujawski, course professor
8. S. Sood Joshi, C. Desormaux, *How has the Big-data altered our built environment?* , students of Eco Design, Algonquin College, 2018, W. Kujawski, course professor
9. S. Salat et al, *Cities and Forms*, 2011, Hermann Editeurs des Sciences et des Arts
10. S.Salat , L.Bourdic, and C. Nowacki, A*ssessing Urban Complexity*, 2010
11. G. Mangone *Constructing hybrid infrastructure: Exploring the potential ecological, social, and economic benefits of integrating municipal infrastructure into constructed environments,* 2015
12. Larsson N., Salat S., *Performance Synergies in Small Urban Zones*, 2013.
13. Pollard D., *Corelation of Infrastructure and Nature,* Article for American Institute of Architects, 2016.
14. CMHC, *Southeast False Creek Integrated Design Process Workshops.* http://www.cmhc-schl.gc.ca/odpub/pdf/65350.pdf and Southeast False Creek Design Charrette: Exploring High Density, Sustainable Urban Development. http://www.cmhc-schl.gc.ca/odpub/pdf/62494.pdf.
15. CMHC, *BO01 Sustainable Housing Development.* http://cmhc.ca/en/inpr/bude/himu/inbu/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=60456.
16. CMHC, *Equilibrium™. Project Profile: Now House™*, Toronto, Ontario http://cmhc.ca/en/inpr/su/eqho/noho/upload/NowHouse_en.pdf
17. CMHC, *Benny Farm Redevelopment.* http://cmhc.ca/en/inpr/bude/himu/inbu/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=119486.
18. Holcim Foundation, *Greening the Infrastructure at Benny Farm*, Montreal, Quebec http://www.holcimfoundation.org/T386/Projectgallery-BennyFarmMontreal.htm.
19. L'Oeuf. *Green Energy Benny Farm.* http://www.loeuf.com/projects/gebf/index.php.en
20. CMHC, *BO01 Sustainable Housing Development.* http://cmhc.ca/en/inpr/bude/himu/inbu/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=60456.
21. CMHC, *Equilibrium™. Project Profile: Now House™*, Toronto, Ontario http://cmhc.ca/en/inpr/su/eqho/noho/upload/NowHouse_en.pdf
22. CMHC, *Benny Farm Redevelopment.* http://cmhc.ca/en/inpr/bude/himu/inbu/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=119486.
23. Holcim Foundation, *Greening the Infrastructure at Benny Farm*, Montreal, Quebec http://www.holcimfoundation.org/T386/Projectgallery-BennyFarmMontreal.htm.
24. L'Oeuf. *Green Energy Benny Farm.* http://www.loeuf.com/projects/gebf/index.php.en
25. The Challenge Series, *Millennium Water: The Southeast False Creek Olympic Village.* http://www.thechallengeseries.ca/chapter-01/.
26. City of Vancouver, *Southeast False Creek*. http://vancouver.ca/commsvcs/southeast/.
27. CMHC, *Southeast False Creek Integrated Design Process Workshops.* http://www.cmhc-schl.gc.ca/odpub/pdf/65350.pdf and Southeast False Creek Design Charrette: Exploring High

Density, Sustainable Urban Development. http://www.cmhc-schl.gc.ca/odpub/pdf/62494.pdf.
28. Dockside Green Development, http://docksidegreen.com/
29. Sustainable Architecture & Building Magazine. *SAB Award Winner – Dockside Green.* http://www.sabmagazine.com/blog/2009/06/05/sab-awards-winner-dockside-green/.
30. Sustainable Architecture & Building Magazine. July-August 2009. http://www.sabmagazine.com/blog/2009/06/05/sab-awards-winner-dockside-green/.
31. Toronto Community Housing. *Regent Park.* http://www.torontohousing.ca/regentpark.
32. Fulmer, J., *What in the world is infrastructure?". PEI Infrastructure Investor (July/August),* 2009
33. Brown I., Kellenberg S., *Ecologically Engineering Cities through Integrated Sustainable Systems Planning,* Journal of Green Building, 02/2009
34. Tillie N. et al. 2009a. REAP, *Towards CO_2 neutral urban planning*, 45th ISOCARP Congress 2009.
35. Pratt R.G. et al., *The Smart Grid: An Estimation of the Energy and CO_2 Benefits*, U.S. Department of Energy Revision 1, 2010.
36. Tillie N. et al. 2009b, *REAP Rotterdam Energy Approach and Planning, Towards CO2 – neutral* urban Development, Rotterdam.
37. BioRegional Development Group, *Beddington Zero Energy Development*, 2002.
38. CMHC, Green Roofs: *A Resource Manual for Municipal Policy Makers,* 2006, https://www03.cmhc-schl.gc.ca/catalog/productDetail.cfm?lang=en&cat=123&itm=73&sere=2&start=1&stfl=green%20roof&fr=1495130589887 [access: March 2017].
39. CMHC, *Innovative Buildings*: *Klosterenga*, Oslo, Norway. http://www.cmhc-schl.gc.ca/en/inpr/bude/himu/inbu/upload/66356_W.pdf.
40. CMHC, *Giving Pedestrians an Edge—Using Street Layout to Influence Transportation Choice*, http://www.cmhc-schl.gc.ca/odpub/pdf/66086.pdf,
41. Taming the Flow—Better Traffic and Safer Neighbourhoods, http://www.cmhc-schl.gc.ca/odpub/pdf/66071.pdf,
42. Adapted from CMHC's Breaking New Ground: A Fused Grid Neighbourhood in Calgary, http://www.cmhc-schl.gc.ca/odpub/pdf/66337.pdf, p. 7.\
43. Natural Resources Canada, *Photovoltaic potential and solar resource maps of Canada*. https://glfc.cfsnet.nfis.org/mapserver/pv/index.php.
44. Pearl D., Wentz D. *Benny Farm and Rosemont - Community-inspired housing in Canada*, 2014 www.holcimfoundation.org/canada
45. Chicago Architecture Info. *The Willis Tower*. www.chicagoarchitecture.info/Building/375/The_Willis_Tower.php.
46. Smith + Gill Architecture. http://www.smithgill.com/ - /work/willis_tower.
47. Tomalty, Ray. *The Ecology of Cities*. Alternatives Magazine. 35.4 2009. http://www.alternativesjournal.ca/articles/the-ecology-of-cities.
48. Program on Water Governance. http://www.watergovernance.ca/. Watersave: The Network for Water Conservation and Recycling. Barriers to Grey Water Recycling. http://www.watersave.uk.net/Presentations/Sandra_2.ppt.
49. Manitoba Hydro Building http://www.hydro.mb.ca/corporate/mhplace/quick_facts_building.shtml2009 Best Tall Building Americas".
50. Council on Tall Buildings and Habitat, *Manitoba Hydro Place*, Smith Carter Architects
51. R. M. DeKay, *Climatic Urban Design: configuring the urban fabric to support daylighting, passive cooling, and solar heating*, GreenVision Studio, School of Architecture, Univ. of Tennessee, USA, Sustainable Cities 2012, 7 - 9 May 2012, Ancona, Italy
52. M. Gorgolewski, J. Komisar, J. Nasr , *Carrot City Creating Places for Urban Agriculture*, 2011
53. D-L.Smith, *Carrot City: Designing for urban agriculture*, 2010
54. Tillie, N. et al. 2009a. REAP, *Towards CO_2-neutral urban planning.* 45th ISOCARP Congress 2009.
55. J. Stroman-Andersen, P.A. Sattrup, *The urban canyon and building energy use: Urban density versus daylight and passive solar gains*, Energy and Buildings 42, 2011
56. R. Rovers, *Harvesting Urban Space*, University of Wageningen, the Netherlands, 2006,

57. Ted Kesik, Ivan Saleff, *Tower Renewal Guidelines,* University of Toronto, 2009,
58. Ted Kesik, 2010, *Tower Renewal – Strategies for Improving the Performance of our Aging Building Stock*, seminarum BECOR (Building Envelope Council Ottawa Region)
59. Ceres, *From Risk to Opportunity: Insurer Responses to Climate Change,* 2009, http:// insurance.lbl.gov/opportunities/risk-to-opportunity-2008.pdf [access: March 2017].
60. Low Energy Architecture Research Unit. London Metropolitan University. http://www.learn.londonmet.ac.uk/packages/cdres/projects/p2/en/over/over_1.html
61. M. Gorgolewski, *Energy Efficiency and the UK Building Regulations.*
62. M. Rosen, W.Leong, M. Le, *Modelling and analysis of building systems that integrate cogeneration and district heating and cooling*
63. A. Bernheim, S. Lewis, *Measure and Cost of Green Building*, - AIA National Convention, May 2000
64. L.Zeiher, *The ecology of Architecture*
65. S. Mendler, W. Odell, *The HOK guidebook to Sustainable Design*
66. R. Cole, *Cost and Value in Building Green*
67. W.Bordass, *Cost and value: fact and fiction*
68. N. Larsson, J. Clark, *Incremental costs within the design process for energy efficient buildings,*
69. Tomalty, Ray, *The Ecology of Cities*, Alternatives Magazine, 35.4 2009.
70. Grammenos F., Lovegrove G.R. *Remaking the City Street Grid. A Model for Urban and Suburban Development, 2015*
71. D. Heim, W. Witkowski, *Wisdom of traditional rural architectureas the guidelines for designing contemporary bioclimatic buildings*, Lodz 2000
72. *Climate Change and Insurance,* http://www.cbc.ca/beta/news/business/insurance-climate-change-adaptability-1.3323132 , 2016
73. http://www.dlsc.ca/ - Drake Landing web site
74. https://energy.gov/eere/buildings/building-technologies-office - community in Livermore, CA
75. http://www.inhabitat.com/
76. https://www.iisd.org/business/viewcasestudy.aspx?id=77 [access: March 2017].
77. http://vancouver.ca/home-property-development/southeast-false-creek- neighbourhood-energy-utility.aspx [access: March 2017].
78. http://www.willistower.com/building-information/sustainability [access: March 2017].
79. https://traveldigg.com/willis-tower-the-chicagos-skyscraper [access: March 2017].
80. http://www.solaripedia.com/13/247/2607/dockside_green_water_feature.html [access: March 2017].
81. www.googleearth.pl [access: March 2017].
82. http://urbantoronto.ca/news/2015/05/scale-model-regent-park-gives-insight-future [access: March 2017].
83. https://www1.toronto.ca/city_of_toronto/city_planning/community_planning/ files/pdf/regentpark_planning-rationale.pdf [access: March 2017].
84. http://www.fvbenergy.com/projects/regent-park-community-energy-system [access: March 2017].
85. http://www.ecotek.ca/ECO-TEK_Ecological_Technologies/Home.html [access: March 2017].
86. http://www.bioregional.com/beddington-zero-energy-development-case-study- report [access: March 2017].
87. https://goo.gl/images/yADkxz [access: March 2017].
88. https://www.cmhc-schl.gc.ca/en/inpr/su/eqsucoin/eqsucoin_003.cfm [access: March 2017].
89. https://www.cmhc-schl.gc.ca/odpub/pdf/67063.pdf [access: March 2017].
90. https://www.cmhc-schl.gc.ca/odpub/pdf/66071.pdf [access: March 2017].
91. https://www.cmhc-schl.gc.ca/odpub/pdf/63760.pdf [access: March 2017].
92. http://www.cscd.gov.bc.ca/lgd/greencommunities/sustainable_development.html [access: March 2017].
93. U.S. Environmental Protection Agency, Many Reasons to Build Green on Brownfields. http://epa.gov/swerosps/bf/policy/lessons_learned.pdf.

94. http://www.smithcarter.com/projects/urban_impact/workplace/manitoba_hydro/
95. http://www.oaa.on.ca/professional+resources/sustainable+design/manitoba+hydro+place
96. http://www.hydro.mb.ca /mhplace
97. http://manitobahydroplace.com/integrated-elements/ie-details/?rid=33
98. http://www.cscd.gov.bc.ca/lgd/greencommunities/sustainable_development.htm , accessed March 2017

CMHC created its **Life Cycle Costing Tool for Community Infrastructure Planning** to help owners and developers estimate the approximate costs of development and to compare alternative development scenarios (currency may not matter). It allows to consider the life cycle costs of development, (over a 75-years) and can be used for a variety of project sizes, from infill to subdivisions, and looks at a number of different costs such as:

- Hard infrastructure such as roads, sewers, etc.
- Municipal services such as transit and waste management
- Private user costs, including driving and home heating costs
- External costs such as air pollution and climate change

The tool is available for free at this address:
http://www.cscd.gov.bc.ca/lgd/greencommunities/sustainable_development.htm , accessed March 2017

Table of figures