ECOSYSTEM SERVICE ASSESSMENT OF GREEN ROOFS IN BANGKOK

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รัตนพรรณ ภูมิรัตน์ : การประเมินการบริการของระบบนิเวศของหลังคาเขียวในกรุงเทพมหานคร. (ECOSYSTEM SERVICE ASSESSMENT OF GREEN ROOFS IN BANGKOK) อ.ที่ปรึกษาหลัก : ผศ. ดร.พงษ์ชัย ดำรงโรจน์วัฒนา, อ.ที่ปรึกษาร่วม : ผศ. ดร.นิพาดา เรือนแก้ว ดิษยทัต

หลังคาเขียวเป็นระบบนิเวศที่มนุษย์สร้างขึ้นที่สามารถให้การบริการของระบบนิเวศได้ทั้ง 4 ด้าน ได้แก่ ด้านการควบคุม ด้านการเป็นแหล่งผลิต ด้านสังคมวัฒนธรรมและด้านการสนับสนุน อย่างไรก็ตาม งานวิจัยส่วนใหญ่เน้นศึกษาการบริการของระบบนิเวศด้านการควบคุม และทำการประเมินการบริการของระบบนิเวศด้านต่าง ๆ แบบแยกกัน นอกจากนี้ยังขาดเครื่องมือสำหรับการประเมินการบริการของระบบนิเวศที่ครอบคลุมทุกด้านและสามารถนำผลการประเมินของแต่ละด้านมาเปรียบเทียบกัน ซึ่งทำให้เกิดความยากลำบากในการปรับปรุงการบริการของระบบนิเวศของหลังคาเขียว ดังนั้น งานวิจัยนี้จึงมีวัตถุประสงค์เพื่อ (i) ประเมินการบริการของระบบนิเวศของหลังคาเขียว 7 แห่งในกรุงเทพมหานครโดยใช้วิธีการวัดโดยตรง และการใช้แบบประเมินอย่างรวดเร็ว, (ii) ศึกษาทัศนคติของประชาชนต่อหลังคาเขียวและการบริการของระบบนิเวศของหลังคาเขียวโดยใช้แบบสอบถามและการสัมภาษณ์เพื่อรวบรวมข้อมูลจากนิสิตนักศึกษา คนวัยทำงาน และผู้เชี่ยวชาญด้านหลังคาเขียว จำนวน 259, 90 และ 5 คน ตามลำดับ และ (iii) สร้างเกมและสถานการณ์จำลองเพื่อเป็นเครื่องมือสำหรับแลกเปลี่ยนความรู้เรื่องหลังคาเขียวสู่ประชาชนทั่วไปและผู้มีส่วนเกี่ยวข้อง ผลจากการประเมินการบริการของระบบนิเวศโดยใช้วิธีการวัดโดยตรงพบว่าหลังคาเขียวในการศึกษานี้สามารถให้การบริการของระบบนิเวศได้ทั้ง 4 ด้าน ผลจากการประเมินการบริการของระบบนิเวศโดยใช้แบบประเมินอย่างรวดเร็วพบว่าคะแนนการบริการของระบบนิเวศของหลังคาเขียวทั้ง 7 แห่ง มีคะแนนตั้งแต่ 48 ถึง 74 คะแนน จากคะแนนเต็ม 100 คะแนน โดยหลังคาเขียวของโรงแรม อนันตรา สยาม กรุงเทพฯ ได้รับคะแนนการบริการของระบบนิเวศโดยรวมทั้งหมดสูงที่สุด นอกจากนี้ยังพบว่าบริการของระบบนิเวศด้านต่าง ๆ มีทั้งแบบที่ส่งเสริมกัน และแบบได้อย่างเสียอย่าง บริการของระบบนิเวศที่แตกต่างกันนี้ได้รับอิทธิพลมาจากโครงสร้างและการออกแบบของหลังคาเขียว และการจัดการหลังคาเขียว จากการศึกษาโดยใช้แบบสอบถามและการสัมภาษณ์ นิสิตนักศึกษาให้การควบคุมก๊าซเป็นบริการของระบบนิเวศที่สำคัญที่สุด ในขณะที่คนวัยทำงานและผู้เชี่ยวชาญด้านหลังคาเขียวจัดอันดับให้การควบคุมสภาพภูมิอากาศเป็นบริการที่สำคัญที่สุด นอกจากนี้ยังพบว่ามีผู้ตอบแบบสอบถามเพียง 44% ที่ทราบคำจำกัดความของหลังคาเขียว ซึ่งผลการศึกษาข้างต้นทั้งหมดถูกนำมาประกอบการสร้างเกมและสถานการณ์จำลอง “บริการของระบบนิเวศของหลังคาเขียว” และใช้ทดสอบกับนิสิตนักศึกษาและผู้เชี่ยวชาญด้านหลังคาเขียวจำนวน 18 รอบ (449 คน) ผลการวิเคราะห์แบบทดสอบก่อนและหลังเล่นเกม พบว่าความรู้ด้านหลังคาเขียวผ่านของผู้เล่นเพิ่มขึ้นอย่างมีนัยสำคัญ งานวิจัยนี้จึงมีส่วนสำคัญต่อการศึกษาเรื่องบริการของระบบนิเวศของหลังคาเขียวในอนาคต โดยการนำเสนอแนวทางใหม่ในการประเมินบริการของระบบนิเวศ และนวัตกรรมเกมและสถานการณ์จำลองสำหรับการแลกเปลี่ยนเรียนรู้และสร้างความตระหนักเกี่ยวกับการบริการระบบนิเวศของหลังคาเขียว

สาขาวิชา	วิทยาศาสตร์ชีวภาพ	ลายมือชื่อนิสิต ....
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Rattanapan Phoomirat : ECOSYSTEM SERVICE ASSESSMENT OF GREEN ROOFS IN BANGKOK. Advisor: Asst. Prof. PONGCHAI DUMRONGROJWATTHANA, Ph.D. Co-advisor: Asst. Prof. NIPADA RUANKAEW DISYATAT, Ph.D.

Green roofs are constructed ecosystems that can provide four main types of ecosystem services (regulating, provisioning, cultural, and supporting services). However, most green roof studies have focused on the regulating services and each ecosystem service type was usually evaluated separately. Moreover, there is a lack of assessment tool that can provide comparable outputs of total and different ecosystem services on green roofs, resulting in the difficulty to improve ecosystem service provision by green roofs. Therefore, this research aimed to (i) assess four main categories of ecosystem services provided by seven green roofs in Bangkok using direct measurement techniques and a novel rapid assessment checklist, (ii) investigate perception of people on green roofs and their ecosystem services using questionnaires and interviews with three groups of respondents; 259 university students, 90 workers, and five experts, and (iii) create a “Green roof ecosystem service” game for sharing the green roof knowledge with the public and concerned stakeholders. The results from the direct measurement showed that the selected green roofs in Bangkok could provide a combination of four main types of ecosystem services. The results from the rapid assessment checklist showed that the ecosystem service scores of seven sites ranged from 48 to 74 points from a maximum of 100. The green roof on Anantara Siam Bangkok hotel received the highest score of total ecosystem services of 74 points. Tradeoff and synergy among different green roof ecosystem services were observed. Different ecosystem services were influenced by green roof structure and design and management. Through the questionnaires and interviews, gas regulated was ranked as the first priority of ecosystem services ranked by the university students while the workers and experts cited climate regulation as the ecosystem service of the highest priority. Only 44% of the respondents knew the definition of the green roof. All of these results were used to create a series of green roof games which were used during gaming sessions with university students and experts. The results from pretest- posttest analysis from 18 gaming sessions, 449 participants, showed a significant improvement of green roof knowledge through playing the games. In summary, this research has contributed valuable knowledge of ecosystem services on green roofs by providing a convenient framework to assess ecosystem services and an innovative gaming and simulation for sharing the knowledge and raising awareness of the green roof ecosystem services.

Field of Study:	Biological Sciences	Student's Signature ....
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CHAPTER I

INTRODUCTION

1.1. Rationale

Green area is an important element in urban landscape and it can play a role in providing ecosystem services and improving environmental quality of cities (Rall et al., 2015). Therefore, more green areas are being installed in many cities worldwide, both on the ground and on building rooftops, as known as green roofs. Green roof is a technology enabling growth of vegetation and growing media on rooftops (Oberndorfer et al., 2007). Hence, green roofs can mimic natural ecosystems structurally and functionally.

Green roofs can provide several ecosystem services, usually a combination of regulating, provisioning, supporting and cultural services (Chang et al., 2017). Humans obtain various ecological and environmental benefits from a green roof ecosystem (Berardi, GhaffarianHoseini, and GhaffarianHoseini, 2014). For instance, green roofs usually reduce building temperature and surface heat (Sfakianaki et al., 2009), decrease the energy consumption in the building (Stone, Vargo, and Habeeb, 2012), absorb atmospheric carbon dioxide which is the important greenhouse gas (Getter et al., 2009), preserve the diversity of plants (Cook-Patton and Bauerle, 2012), and function as the habitat for animals such as birds (Fernandez-Cañero and González-Redondo, 2010). In addition, green roofs can provide much-needed space for vegetable production in urban communities (Whittinghill, Rowe, and Cregg, 2013).

A review of recent literature about ecosystem services on green roofs in the ISI Web of Sciences (http://www.isiknowledge.com) showed that most studies have focused on the regulating services and only one ecosystem service type was usually evaluated individually. Therefore, these assessments could not offer the complete evaluation of ecosystem services on green roofs because only selected services were evaluated. Nevertheless, relationships and trade-offs among ecosystem services in general can happen (Rodríguez et al., 2006). Therefore, several ecosystem services should be investigated together to enhance the understanding of the role of green roofs as a provider of ecosystem service.

The green roof design and management can be divided into two approaches, namely ecosystem-based and human requirement-based green roof designs. The objective of the ecosystem-based design proposes that the more ecosystem services are served, the better quality of urban life is (Bolund and Hunhammar, 1999). Therefore, green roofs with a good potential in providing four main categories of ecosystem services are highly recommended. However, in practice, most of the green roofs are usually constructed based on the requirements from human inhabitants, therefore, the initial objective for green roof construction is to satisfy human needs, such as recreational benefits. Moreover, some limitations of the green roof, such as limited resources and green roof structure can possibly limit multiple ecosystem services. This can lead to disappearance or poor performance of some ecosystem services, such as food production in provisioning services.

Although green roof technology has received increasing attention and has been promoted in several countries, the popularity of green roof in Thailand is still limited. Bangkok is one of the cities where green spaces have been replaced by vertical buildings. In 2018, the proportion of green space per person was about 6.70 m^2 (Environment department of The Bangkok Metropolitan Administration, 2019) and it is rather small, being less than 9 m^2 per person of the international standard (World Health Organization, 2010). There have been continuous attempts to increase green space in Bangkok through parks and green roofs. However, the benefits of green roofs have not been comprehensively evaluated. The research about green roofs in Thailand was rarely found. Only two studies on the influential factors for green roof construction in Thailand and the energy saving potential of green roofs have been reported (Permpituck and Namprakai, 2012; Sangkakool et al., 2018). Apart from that, based on the preliminary observation, the green roofs in Thailand seem to be constructed for satisfying the human requirements, then the intended functions of most green roofs are provision of recreational space and aesthetic value. Other aspects of ecosystem service provided by green roofs seemingly get less recognition from the public. Therefore, in order to increase greater recognition and consideration of the relevant stakeholders about the ecosystem-based green roof design and management, the ecosystem services on green roofs have to be assessed.

Tools for ecosystem service assessment have to be selected carefully for the investigation so that the results would effectively reflect the potential in green roofs ecosystem service provision. Several conventional tools for ecosystem service assessment have been developed and used in natural ecosystems. Ecosystem Services Review (ESR), is a qualitative tool used for ecosystem service identification, prioritization, and assessment (Hanson et al., 2012). Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) has been used to evaluate the ecological production and subsequent economic valuation (Sharp et al., 2016). Toolkit for Ecosystem Service Site-based Assessment (TESSA) is a suite of tools for ecosystem services assessment and monitoring at a site scale (Peh et al., 2013). Additionally, various empirical methods were also used for ecosystem service valuation. For example, carbon sequestration and runoff retention were measured as representative regulating services (Coskun Hepcan and Hepcan, 2018). Number of plant and animal species found on study sites were evaluated and used as indicators for supporting services (Baral, Guariguata, and Keenan, 2016).

Current assessment tools have a limitation in aggregation of ecosystem services because different ecosystem services are measured in different units. Some services, particularly cultural services, are qualitative and have no market value (Daniel et al., 2012). Then, they cannot be aggregated with the market values from other services. Alam, Dupras, and Messier (2016) developed a new framework called Ecosystem Services Composite (ESC) for assessing urban ecosystem services using composite indicators. Each ecosystem service value is transformed into common units before the final aggregation. Then, ecosystem service values from this framework are presented in a single value which can be compared across study sites and situations. Presently, no assessment tool exists specifically for evaluation of ecosystem services of green roofs, which are greatly needed in order to understand urban ecosystems currently expanding in several parts of the world. A tool for ecosystem service assessment can help identify strong and weak points of existing green roofs; moreover, it can be used to design a new green roof with the high potential in ecosystem service provision. Hence, ESC framework will be used for construction of a rapid assessment tool for green roof ecosystem services.

In addition to the ecological aspect (green roof ecosystem services), the societal aspect in terms of perception of stakeholders, such as green roof owners and general public, on green roofs and their ecosystem services should be investigated since green roofs are the man-made ecosystem. Moreover, the green roof owners generally play the important role in green roof design and management. They can decide whether to improve the poor ecosystem services or not because some services are probably not suitable or necessary from their perspectives. Then, it will be better for planning and management of green roofs if people perception is known. Furthermore, to increase the understanding about green roofs, the green roof knowledge needs to be communicated to the public and relevant stakeholders.

Companion modelling approach (ComMod) is a highly interactive collaborative or participatory modeling process. This approach can help stakeholders to share their knowledge and make a collective decision through a model that represent the situation of their socio-ecological system (Barreteau et al., 2003). There is a distinction between collaborative and participatory modeling. Collaborative modeling includes co-designing and/or joint decisions of key stakeholders in the modeling process while participatory modeling is consisted of broader levels of participation and types of cooperation (Basco-Carrera et al., 2017). Therefore, due to the difficulty for participation of some key stakeholders for co-designing process in this study, the participatory modeling was applied. Gaming and simulation process are one of tools in ComMod that usually used for various management issues. Gaming and simulation process involving a role-playing game (RPG) could be used successfully for learning process in water management (Abrami et al., 2012). Therefore, the simulation process was chosen to create RPG of green roofs in order to share green roof knowledge in ecosystem service aspect to the public.

Hence, this research aims to evaluate four main categories of ecosystem services found on green roofs in Bangkok using both direct and rapid assessment tools and to construct a collaborative model for transferring the knowledge of green roof ecosystem services. In summary, the outcomes of this research are expected to fill the knowledge gap about green roofs in both ecology and social aspects. Furthermore, this study will contribute to the increasing knowledge of ecosystem services served by green roofs in a tropical city.

1.2. Research questions

1. Which design of green roof can provide the most various and optimal quality of ecosystem services?
2. Can the participatory modeling help the people to know more about green roof technology and realize about ecosystem based green roof construction?

1.3. Objectives

1. To assess the ecosystem services of green roofs using a developed rapid assessment checklist and empirical methods
2. To identify the priority and perception of green roof ecosystem services in Bangkok
3. To construct a participatory modeling process for knowledge sharing and co-learning of green roof ecosystem services

1.4. Dissertation framework

This dissertation is divided into three major parts: (1) Ecosystem service (ES) assessment of selected green roofs in Bangkok, which include the four ecosystem service types: regulating services (RS), provisioning services (PS), cultural services (CS) and supporting services (SS); (2) Priority and perception of ecosystem services on green roofs; and (3) Gaming and simulation (Figure 1.1)

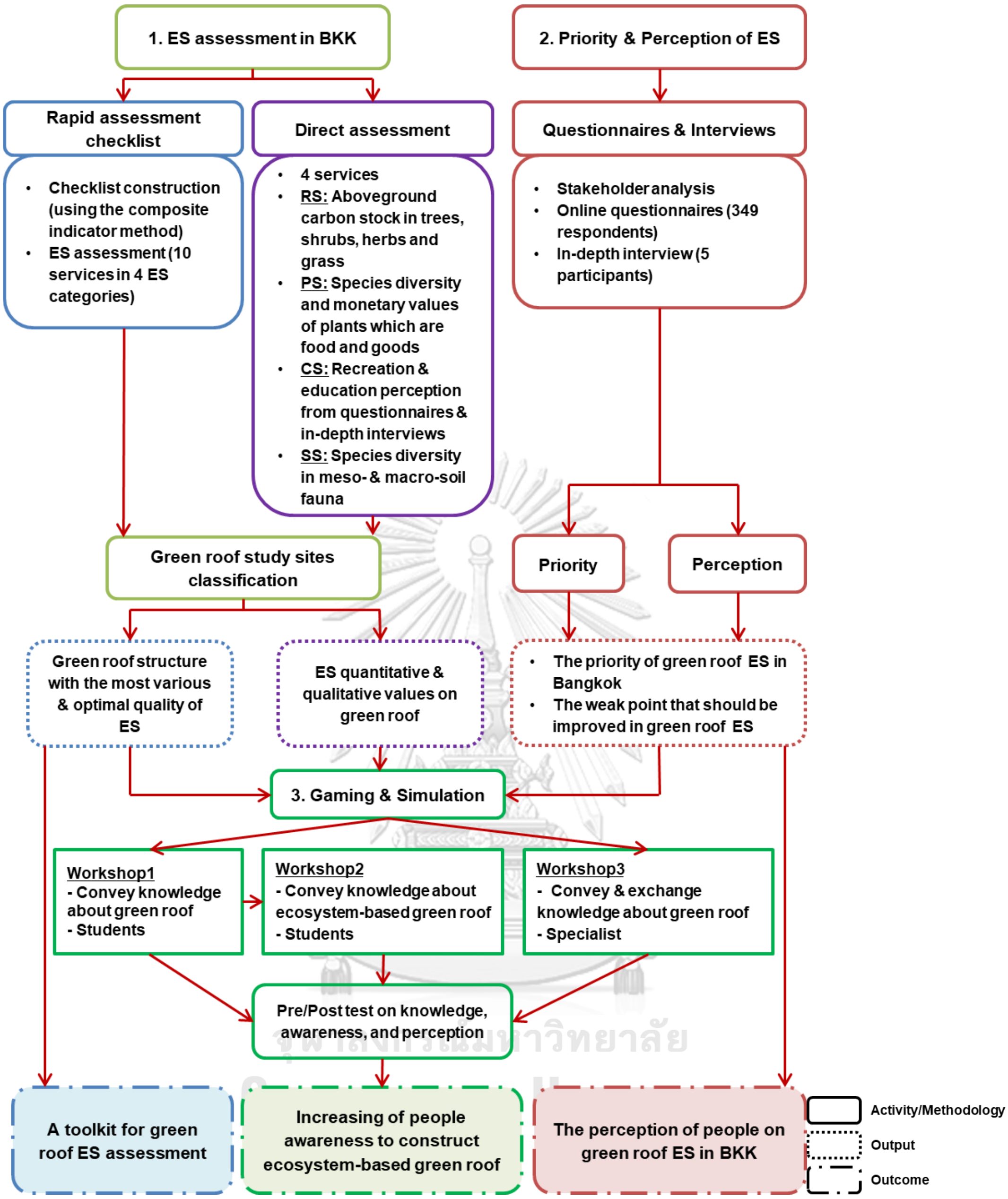


Figure 1.1 The dissertation framework to assess ecosystem services on green roofs

CHAPTER II

LITERATURE REVIEWS

2.1. State of the arts of green roofs

2.1.1. Definition and characters of green roofs

Green roofs are an installation of vegetation on a rooftop. In the beginning, the major purpose of green roofs was the mitigation of temperature, specifically by reducing building temperature in summer and maintaining roof thermal insulation in winter (Theodosiou, 2009). Green roofs can play the role as manmade ecosystems that can provide several benefits in many aspects including environmental and aesthetic aspects (Besir and Cuce, 2018). Economic benefits can be also provided by green roofs (Shafique, Kim, and Rafiq, 2018). Recently, many roofs are also defined as green roofs, such as living roofs, rooftop garden, eco roofs, and vegetated roofs (Shafique et al., 2018). Green roofs are a part of green infrastructure or green building, which is defined as the combination of green area and constructed systems (Demuzere et al., 2014).

Construction of green roofs requires that the roofs are covered by substrate and vegetation. Green roof structure actually consists of several components including vegetation of various species and lifeforms, substrate, filter and drainage layers, special layers for building structure protection including protection layer, root barrier, insulation layer and water proofing membrane, and roof deck (Besir and Cuce, 2018) as shown in Figure 2.1.

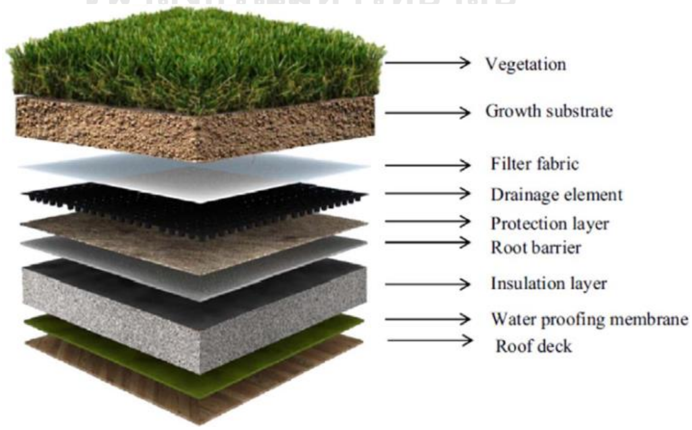


Figure 2.1 Green roof structure
(Source: https://ars.els-cdn.com/content/image/1-s2.0-S1364032115015026-gr1_lrg.jpg)

Green roofs are classified into four types based on vegetation, maintenance and structure, namely extensive green roofs, simple-intensive or semi-intensive green roofs, biodiverse, and intensive green roofs, (Catalano et al., 2018). Figure 1.3 presents the appearance of each green roof type.

Extensive green roofs are the simplest green roof type with 6-20 cm of substrate thickness. They sometimes can be called as eco-roof (Theodosiou, 2009). Plants that are generally used on this type of green roofs should be native species and have some special characteristics including stress tolerance, regeneration and easy propagation. Mosses, succulents, forbs and grasses can be found on this green roof type. Therefore, the extensive green roofs require the lowest maintenance, resulting in relatively lowest cost for installation and maintenance. They usually are designed to be inaccessible.

Simple-intensive or semi-intensive green roofs are similar to extensive green roofs, but usually contain more diversity and density of vegetation. Substrate depth is 12-100 cm, allowing the growth of shrubs, perennials herbs, and lawns. Semi-intensive green roofs require higher installation and maintenance costs than extensive green roofs. They are designed to be occasionally accessible.

Biodiverse green roofs are an intermediate typology between simple-intensive and extensive green roofs. They are constructed for recreating habitats for plants and faunas. Therefore, they are consisted of different substrate thickness, various substrate types (e.g. sand and gravel), multiple layers of structural elements for habitat provisioning (e.g. trunks and boulders). Then, this results in the spontaneous development of plants, the reduction of maintenance requirement, and the creation of bare area to mimic brownfields.

Intensive green roofs usually have the most diverse vegetation which sometimes can be similar to gardens at the ground level. Trees, shrubs, perennials herbs, and lawns are grown on the substrate of 50-200 cm thickness. The users can access to the green roof. Therefore, they can provide recreation service comparable to ground-level gardens and they often are called as a roof garden. However, the limitations of this type of green roof are loading capacity of structure and total cost. This green roof type is the most expensive in both installation and maintenance costs because of the most complex structure and other requirements including irrigation and maintenance.

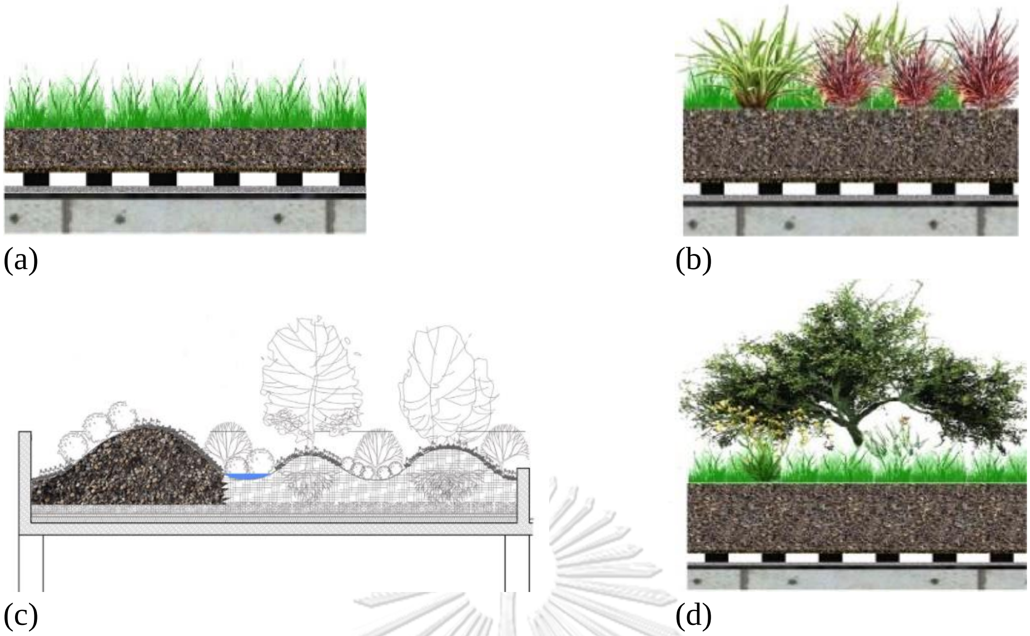


Figure 2.2 Green roof types: (a) Extensive green roof, (b) Simple-intensive or Semi-intensive green roof, (c) Biodiverse, and (d) Intensive green roofs
(Source: https://www.buildup.eu/en/learn/ask-the-experts/which-are-different-types-green-roofs and https://ars.els-cdn.com/content/image/3-s2.0-B9780128121504000227-f22-03-9780128121504.jpg)

2.1.2. Research on green roofs

Green roofs have been popularly used in many countries in the last decade. Green roof research is an interdisciplinary study and it is usually composed of natural sciences, architecture and engineering expertise (McIntyre and Snodgrass, 2010). The following are directions of green roof research in general while the researches on green roof benefits and ecosystem services are reviewed in the ecosystem service part of literature review (2.2.2).

Recently, the research related to green roofs has increased with the needs for providing knowledge for urban planning and management. The research works are not distributed evenly in terms of geographical locations. About 66% of the total green roof research papers between 2001-2012 have been conducted in the temperate regions, specifically the United States and the European countries (Blank et al., 2013). Therefore, the limited research in tropical regions is proposed as a gap in the green roof research. In addition, little green roof research in developing countries can result in lack of awareness of green roof benefits; therefore, the knowledge about green roof benefits should be shared and transferred to building owners and people involved in order to encourage the construction and use of green roofs (Shafique et al., 2018).

More recently, interests have increased in green roof research in several Asian countries. In China, more green roofs have been installed in rapidly expanding cities. Green roof characteristics were examined in China, including vegetation, structures, substrate, ecological benefits and building cooling effects of green roofs (Xiao et al., 2014). Green roof research and projects in South Korea are emphasized; moreover, there are the green roof support projects for private buildings (Kim, 2017). In Hong Kong, green roof researches include application, cost, benefits, and barriers of green roof construction (Townshend and Duggie, 2007; Zhang et al., 2012). In Malaysia, green roof technology was studied for using as a tool for urban regeneration and the perception of green roof users was also investigated in order to encourage the participation of people in designing and creating public green spaces (Taib and Abdullah, 2012; Rahman et al., 2015).

2.1.3. Policies in several countries to encourage green roof application

Different policies are created and applied in several countries in order to encourage green roof construction. The policies are normally comprised of laws, regulations, financial and tax incentives, or reduction in water or property fees (Shafique et al., 2018). Laws and regulations are used in various countries. In France, the green rooftop law calls for construction of green roofs on new buildings located in the commercial zone (Hoag, 2015). In Tokyo, Japan, private and public buildings with the total area larger than 1000 m^2 and 250 m^2, respectively, must have green roof installation (Brenneisen, 2004). Green roof construction is required by law on the flat roofs with surface area larger than 100 m^2 in Munich, Germany. In Canada, green roofs are required on new buildings with area larger than 200 m^2 in Toronto, and new commercial and industrial buildings with area larger than 5,000 m^2 in Vancouver (Shafique et al., 2018).

In addition to laws and regulations, financial incentives have been launched in several countries for supporting the green roof application. Green roof owners in Basel, Switzerland and Esslingen, Germany, are repaid 20% and 50% of the total green roof cost, respectively, while in Darmstadt, green roof owners receive a maximum of € 5000 for green roof installation (Brenneisen, 2004; Shafique et al., 2018). In Quebec, Canada, green roof owners can receive money per square meter of green roof (Carter and Fowler, 2008). In United States, most of the policies have been adopted at the city level. For example, in New York City, owners of buildings with green roof larger than 50% of roof space are given a maximum of $100,000 (or $4.5 per sq./ft) for a one-year tax credit (Berardi et al., 2014). Apart from the countries mentioned above, China, Hong Kong, Malaysia, Singapore, and South Korea, also establish direct or indirect incentive policies for supporting green roof application in urban ecosystems (Shafique et al., 2018).

2.1.4. Green roofs in Bangkok, Thailand

According to the Bangkok Metropolitan Administration's Environment department of The Bangkok Metropolitan Administration (2015), a green roof is defined as a garden or a small park decorated by vegetation and natural materials and located on the rooftop, roof, or any areas in buildings. Then, green roofs can also be called skyrise greenery or rooftop gardens. Based on the above definition, green roofs must have the following attributes:

(1) Green roofs are not located in a room or corridor in the building,
(2) Green roof construction has to be permanent structure,
(3) Vegetation can be planted directly to substrate or grown in flowerpots or other flower containers,
(4) Green roof area should be at least 3 m^2.

The Environment department of The Bangkok Metropolitan Administration (2015) also reported that in 2015 there were 163 sites of green roofs in Bangkok with the combined area of green roofs of 189,765 m^2. However, the proportion of green space from green roofs per person was merely 6.70 m^2 which was far below the WHO's per capita standard of 9 m^2. Therefore, green roofs are included in the strategies for increasing the sustainable green spaces in Bangkok. There are also the regulations and laws about building control and green space issue. Ground level green spaces which need to be more than 50% of total area are required for each building, such as condominium, while the rest green spaces can be located on the building. Then, green roofs are one of the alternative strategies that usually used to accomplish the requirements. (Office of Natural Resources and Environmental Policy and Planning, 2014).

Nevertheless, research with emphasis of green roofs in Bangkok is still limited. There have been only two international publications about energy performance on green roofs and factors influenced green roof application in Thailand (Permpituck and Namprakai, 2012; Sangkakool et al., 2018). At the national scale, research on green roofs has been conducted in various fields, such as engineering, architecture, environment, and ecology. For example, there were the studies about functions of green roofs for mitigating urban heat island (Theetawatwong, 2016), reducing rain noise problems (Tubsuwan, Sunakorn, and Yimprayoon, 2019), providing habitat for birds (Sananunsakul, 2017), and the potential of green roofs in urban green space development (Paradorn, 2015).

2.2. Ecosystem services

2.2.1. Definition and classification of ecosystem services

Ecosystem services are the benefits, in both goods and services, human obtained from ecosystems (Millennium Ecosystem Assessment, 2005). The benefits derive from ecological processes and functions of the ecosystems (de Groot, Wilson, and Boumans, 2002). The following are four main categories of ecosystem services classified by Millennium Ecosystem Assessment (2005):

- Regulating services are the benefits obtained from regulation of essential ecological processes,
- Provisioning services are the products or natural resources provided by ecosystems,
- Cultural services are the nonmaterial benefits provided by ecosystems,
- Supporting services are the important services for supporting the other ecosystem services.

Table 2.1 presents ecosystem services compiled from de Groot et al. (2002), Millennium Ecosystem Assessment (2005), and Sukhdev et al. (2010).

Table 2.1 List of different ecosystem services provided by ecosystems

Main category	Service	Definition
Regulating services	Gas regulation	Contributing chemicals to and extracting chemicals from the atmosphere that can affect air quality and climate
	Climate regulation	Maintaining a preferable climate, such as emitting or storing greenhouse gases
	Disturbance prevention	Mitigating environmental disturbances, such as storm protection and flood prevention
	Water regulation	Regulating runoff, aquifer or river discharge
	Water supply	Storing and provisioning fresh water
	Soil retention	Regulating soil erosion and preventing landslides
	Soil formation	Accumulating of organic matter and maintaining soil fertility
	Nutrient regulation	Storing and re-cycling nutrients
	Waste treatment	Filtering and decomposing organic wastes, detoxifying compounds, or pollutants in water, atmosphere, and soil
	Pollination	Supporting the distribution, abundance, and effectiveness of pollinators
	Pest regulation	Controlling pests
	Disease regulation	Controlling diseases

Main category	Service	Definition
Provisioning services	Food	Providing edible plants, animals, and microbes
	Raw materials	Providing materials, such as wood, silk, and fuel, for human construction and other uses
	Genetic resources	Providing the genes and genetic information
	Medicinal resources	Providing substances for using as traditional medicines or other medicinal uses in the pharmaceutical industry
	Ornamental resources	Providing products for ornamental uses
Cultural services	Aesthetic values	Providing attractive landscape attributes
	Recreation	Providing recreational uses
	Cultural and artistic values	Providing inspiration and appreciation of the natural features of ecosystems
	Spiritual and historic values	Providing spiritual, religions, and heritage values
	Educational values	Providing educational values, such as scientific knowledge
Supporting services	Habitat provision	Providing habitats for plants and animals for living, reproducing, or supporting migration

2.2.2. Ecosystem services provided by green roofs

Several benefits provided by green roofs have been reported and they can be defined as ecosystem services including regulating, provisioning, cultural, and supporting services. However, the review from 252 articles from the ISI Web of Science between 2007-2013 demonstrated that most of the studies focused on regulating services (71%), followed by supporting (25%), provisioning (2%), and cultural services (2%), respectively. In comparison with other services, regulating services of green roofs received the most attention, probably because the green roofs are originally constructed for reducing urban heat island effect and energy use in the building. Moreover, several benefits provided by green roofs can be also classified as regulating services, such as stormwater management (Oberndorfer et al., 2007). The following describe the ecosystem services found on green roofs.

2.2.2.1. Regulating services

A. Gas and climate regulation

Green roof can regulate temperature by providing humidity and shade. Then the building temperature and surface heat which resulted from urban heat island effect can be reduced (Stone et al., 2012). These also result in the decrease of energy consumption in the building (Sfakianaki et al., 2009). Apart from that, vegetation on green roofs can absorb atmospheric carbon dioxide, providing carbon storage (Getter et al., 2009). In other words, green roofs can potentially play a role in mitigating global warming (Ismail et al., 2008).

B. Water regulation and water supply

The substrate layer of green roofs distinguishes them from other traditional roofs. The ability of soils in the substrate layer to absorb rainfall gives rise to the potential of water management ability, including runoff mitigation in the urban landscape (DeNardo et al., 2005). In addition, water quality can also be improved as 95% of water runoff is clean water filtered by the substrate layer and can be reused (Molineux, Fentiman, and Gange, 2009).

C. Waste treatment

Air pollution is the important problem especially in urban area. Green roof vegetation improves air quality by increasing oxygen, reducing carbon dioxide and removing atmospheric pollutants, including ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and particulate matter less than 10 μm (PM_{10}) (Nowak, Crane, and Stevens, 2006). Apart from that, green roofs also have sound filter function (de Groot et al., 2002). The thickness of roof and vegetation layer can abate noise pollution (Van Renterghem and Botteldooren, 2009).

D. Pollination

Green roofs offer habitats for various pollinators, such as bees, which can still effectively pollinate flowering plants on the green roofs as well as perhaps the surrounding plant communities (Ksiazek, Fant, and Skogen, 2012).

2.2.2.2. Provisioning services

Green roofs can function as alternative sites for urban agriculture. Vegetables and crops can be grown on rooftops instead of garden trees or shrubs. Rooftop farms can therefore produce food, increase the agricultural space in urban area, and reduce the cost of vegetable transportation to city (Whittinghill et al., 2013).

2.2.2.3. Cultural services

Rooftop gardens provide an aesthetic landscape where residents can also use for recreation, being a green oasis in the urban ecosystem (Yuen and Nyuk Hien, 2005). Green roof structure, vegetation, and animals found on green roof can be used as sites for relevant scientific research as well as public educational areas (Carter and Fowler, 2008).

2.2.2.4. Supporting services

Green roofs can preserve the diversity of plants (Cook-Patton and Bauerle, 2012) and can become habitat for animals such as birds, insects, and mammals (Clemants et al., 2006; Fernandez-Cañero and González-Redondo, 2010; Madre et al., 2013).

2.3. Techniques for assessment of green roof ecosystem services

2.3.1. Direct assessment

Direct assessment of ecosystem services requires identification of proper units for specific benefits either as relevant amount of materials or economic values of intangible ecosystem services. To measure ecosystem services, multidisciplinary methods are conducted for direct assessment of ecosystem services. Each service can be evaluated differently by suitable methods. Regulation, provisioning, and supporting services are mostly provided in material benefits; therefore, these services can be quantified directly. Several scientific methods are used for ecosystem services evaluation. Indicators and methods used for evaluating each ecosystem service are compiled from several research on green roofs (Table 2.2). For example, carbon storage was used to measure the capacity of greenhouse gases fluxes regulation which is one of the regulating services (Beier, Caputo, and Groffman, 2015). Investigation of species richness and abundance of animals, such as birds and arthropods, was conducted to evaluate supporting services on green roofs in terms of the ability of habitat provision (Partridge and Clark, 2018). While questionnaires and survey were carried out to assess cultural services that provided by urban green space (Ko and Son, 2018). Economic values can be used in the assessment of provisioning services. Gradinaru (2013) suggested that market price is used to estimate provisioning services because the products of provisioning services, such as wood, vegetable, or fruits, mostly have the market price and can be traded.

Table 2.2 Examples of direct indicators and methods conducted for green roof ecosystem service assessment

Ecosystem services	Services	Indicators	Methods	References
Regulating services	Gas regulation	Amount of carbon Sequestration	- Quantifying aboveground biomass - Quantifying belowground biomass - Quantifying substrate carbon content - Quantifying total carbon concentration - Quantifying carbon accumulation	Getter et al. (2009)
		Carbon dioxide concentration	- Measuring CO_2 concentrations - Quantifying CO_2 absorption and emission rates of plants on the green roofs	Li et al. (2010)
	Climate regulation	Heat flux through the roof and temperature	- Using mathematical models	Barrio (1998)
		Temperature	- Measuring surface temperatures - Measuring of ambient air & global temperatures, relative humidity, wind velocity	Wong et al. (2003)
		Urban heat island effect	- Measuring solar radiation - Recording the temperatures - Evaluating of the difference of heat fluxes	Susca, Gaffin, and Dell'Osso (2011)
		Thermal reduction effect of plant layers on rooftops	- Using a climatological model - Calculating the thermal reduction rate	Fang (2008)
	Water regulation	Runoff quality	- Real rain events and artificial rain events experiments - Chemical analysis	Vijayaraghavan, Joshi, and Balasubramanian (2012)
	Water supply	Water retention	- Developing Vegetated Roof Water-Balance Model	Sherrard and Jacobs (2012)
	Waste treatment	Air pollution removal	- Using a dry deposition mode (a big-leaf resistance model)	Yang, Yu, and Gong (2008)
		Urban particulate pollution reduction	- PM10 removal quantification	Speak et al. (2012)
		Reduction of the acoustical facade load from road traffic with green roofs	- Using sound propagation model	Van Renterghem and Botteldooren (2009)

Ecosystem services	Services	Indicators	Methods	References
	Pollination	Pollen limitation	- Determining the rate of spontaneous autogamy - Testing pollen limitation - Collecting insects	Ksiazek et al. (2012)
Provisioning services	Food	Vegetable production	- Collecting products quantitative & qualitative data	Whittinghill et al. (2013)
Cultural services	Ornamental resources	Resident perceptions and expectations of rooftop gardens	- Using a questionnaire	Yuen and Nyuk Hien (2005)
	Aesthetic information	Preferences and perceptions of beauty	- Using a questionnaire	White and Gatersleben (2011)
	Recreation	Number of visitors	- Recording number of green roof visitors	Baral et al. (2016)
	Science and education	Number of educational programs	- Recording number of educational programs conducted on the green roofs	Hernández-Morcillo, Plieninger, and Bieling (2013)
Habitats	Habitat provision	Arthropod diversity	- Testing correlations of vegetation characteristics and insect diversity - Testing correlations of green roofs' overall physical characteristics with arthropod diversity - Collecting insects (pitfall traps) - Collecting soil arthropod	Schindler, Griffith, and Jones (2011)
		Bee communities	- Bee sampling (insect nets & bee bowls)	Tonietto et al. (2011)
		Vegetation diversity	- Measuring the cover-abundance of flowering plants and habitat structural components - Measuring number of species and species richness	Bates, Sadler, and Mackay (2013)

2.3.2. Rapid assessment

Due to the need to encourage the public to have more awareness of the emphasis of green roofs, stakeholders involved, such as building owners, building officers, or gardeners, should participate in the evaluation process. However, some direct assessments for ecosystem service valuation need specific and difficult techniques to evaluate the direct indicators, such as quantifying aboveground biomass to assess amount of carbon storage that can reflect the potential of green roofs in gas regulation. Therefore, the direct assessment might too difficult for the stakeholders to conduct by themselves owing to some limitations, such as technical knowledge used for measurements. A low time requirement for doing the assessment is also favorable because it can be inconvenient for the stakeholders to participate in a time-consuming assessment due to their other responsibilities. Moreover, green roofs are mostly public areas and some direct measurements can disturb the others. Thus, the rapid assessment that is a user-friendly tool and provides adequate information and reliable results is essential for evaluating green roof ecosystem services.

Rapid assessment is defined as a process that is conducted by no more than two people and does not exceed a half day total in the field and another half day for preparation and analysis (Fennessy, Jacobs, and Kentula, 2007). Currently, there are many rapid assessment tools proposed for evaluating ecosystem services of various ecosystems. Peh et al. (2013) proposed a Toolkit for Ecosystem Service Site-based Assessment (TESSA) that is a suite of tools used for evaluating and monitoring ecosystem services at a site scale. The tool can be used to estimate a small number of ecosystem services using field surveys, interviews, questionnaires, and using existing databases and research. Rapid Assessment for Wetland Ecosystem Services (RAWES) has been developed by McInnes and Everard (2017). This approach is a checklist tool for assessing 37 ecosystem services provided by a wetland ecosystem. The indicator questions are used for ecosystem service evaluation. Both rapid assessment tools can provide the valuable information and reliable results; moreover, they can encourage the engagement of stakeholders in a process of ecosystem service assessment. Then, the researcher believed that the outcomes from these rapid assessment tools can help to raise awareness of ecosystem services in public and this can lead to participation of decision-making and making a policy and proper management.

Recently, Alam et al. (2016) proposed Ecosystem Services Composite (ESC) which is a framework of a composite indicator for estimating urban ecosystem services. This approach can transform different variables of each ecosystem service into common units and then a single value of individual and total ecosystem services is performed using the aggregation of variables. Therefore, it is easy for the relevant stakeholders to interpret the results. Furthermore, ecosystem services can be assessed at 2 levels depending on types of indicators, including direct indicators and proxy indicators. Direct indicators are defined as the indicators that can indicate ecosystem services directly and require more measurements. While proxy indicators are the representative indicators which can reflect ecosystem services indirectly. For example, to indicate the potential of gas regulation in regulating services, carbon sequestration and carbon storage are direct indicators while proxy indicators can be the green ratio and existence of woody plants (Pollution Control Department, 2013;

Whittinghill et al., 2014). Hence, the ESC at proxy indicator level is more appropriate and not too difficult for the stakeholders, who possibly have limited technical knowledge. Although this approach poorly demonstrates the relationship between ecosystem components, processes, and services and provides an oversimplification of a complex ecosystem, it presents the potential in supporting a communication with stakeholders in both science and policy aspects due to the easily understandable indicators and results.

2.3.3. Comparison between direct and rapid assessment

Key attributes of direct and rapid assessment are compared (Table 2.3). Several direct assessments are usually conducted by researchers or specialists. Usually a large amount of technical data is needed for assessment process. For example, aboveground and belowground biomass and substrate carbon content have to be collected for estimating total carbon storage potential (Getter et al., 2009). Then, most of the assessment methods are empirical experiments or research, except assessments of cultural services that commonly are use of interview and questionnaires. Thus, in comparison with rapid assessment, high academic knowledge, manpower, and cost and long-time are required for conducting assessment. On the other hand, rapid assessment is a user-friendly method, then it can help support the participation of general users. Therefore, the accuracy and precision of results from the rapid assessment will be compromised. However, recently, the rapid assessment tools have been developed for evaluation of ecosystem services in various ground level ecosystems; moreover, their results are robust and credible enough and also encourage policy and management, such as TESSA and RAWES (Peh et al., 2013; McInnes and Everard, 2017).

Table 2.3 Different attributes found between direct measurement and rapid assessment

Key attributes	Direct assessment	Rapid assessment
User(s)	More suitable for specialists	Specialists/Non-specialists
Data requirement	Medium-High	Low-High
Academic knowledge	Medium-High	Low
Time	High	Low
Manpower	Medium-High	Low
Cost	Medium-High	Low
Output	Intensive	Extensive

2.4. A participatory modeling

2.4.1. Concept of a participatory modeling

A model is defined as a representation of some real-world objects and it can be used for inquiry, such as symbolic models, mental models, and scale models. Moreover, a causal diagram and a protocol for a gaming and simulation are also defined as the model and modeling is a process of construction and/or implementation of a model in which stakeholders might be involved (Bots and van Daalen, 2008). Modeling is consisted of three steps, including requirements analysis, model construction and model use, as presented in Figure 2.3. Modeling can be used as a tool for investigating ecosystem which cannot be conducted a field study due to some reasons, such as political or financial issues (Worrapimphong, Gajaseni, and Bousquet, 2007). Moreover, modeling is usually included in a process of decision-making of natural resource management. Then, stakeholders are engaged in the modeling process. Participatory modeling is one of several types of stakeholder-based modeling (Voinov and Bousquet, 2010).

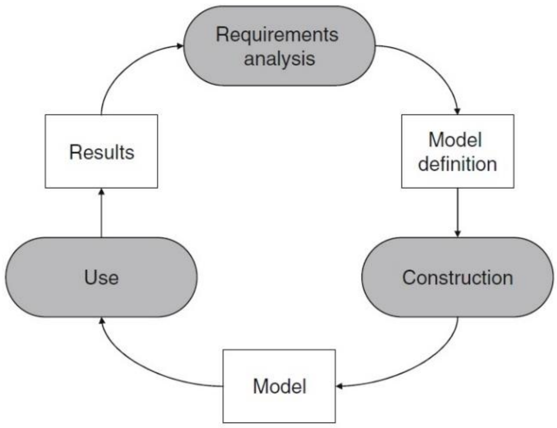


Figure 2.3 Procedure of modeling
(Source: https://link.springer.com/article/10.1007/s11213-008-9108-6/figures/1)

Klaus et al. (2017) proposed the aims and principles of participatory modeling approaches. There are various objectives for conducting participatory modeling, such as to increase understanding of decision problems and complex relationship between socio-economic and ecological dynamics of ecosystems, to clarify the influences of decisions, and to help collective learning and general agreement making. The common principles of participatory modeling are composed of three principles, including iterative learning, emphasis on non-scientists, and the importance of the process. Iterative learning is conducted in participatory modeling; therefore, these approaches focus on learning of stakeholders more than prediction. The importance of comprehension of non-scientists is emphasized. The process of participatory modeling focuses on the created knowledge, the changed behaviors and perceptions, and the improvement of learning. However, the application of participatory model should be varied in accordance with the aims. Furthermore, various types of stakeholders have different roles in participatory modeling Researchers play roles as knowledge providers, process facilitators, and mediators; moreover, model conceptualization and design and participatory workshops collectively with other stakeholders are also conducted by the researchers. While stakeholders can help to design and construct a model in some cases. In addition, they can participate in model calibration, verification and validation stages by providing feedback, validity and usefulness of the model through workshops or questionnaires as well as the assessment of learning process. Then, the stakeholders can be asked for information and can be informants.

In addition to participatory modeling, the term collaborative modeling has emerged and both terms can be used interchangeably due to their inherent similarities (Basco-Carrera et al., 2017). Nevertheless, participatory and collaborative modeling can be distinguished by participation levels and cooperation types. Collaborative modeling requires highly cooperative engagement of key stakeholders; therefore, the key stakeholders usually participate in co-designing and/or joint decisions. Then, collaborative modeling is more suitable for decision-making process with highly collaborative context. While the levels of participation and types of cooperation are widely occurred in participatory modeling. The participation levels are covered from awareness to being involved in discussions and the cooperation types are covered from coordination to joint action. Interested stakeholders are involved in participatory modeling.

2.4.2. Examples of participatory modeling for learning and natural resource management

Klaus et al. (2017) compiled the several influential participatory modeling approaches. Adaptive management is a process of decision-making which developed in ecological researches in order to learn and manage the complex ecosystems and interactions between human and environment and a cyclical learning process is conducted in this approach. Lately, the adaptive management has been implemented through collaborative learning which puts emphasis on stakeholder engagement. Participatory integrated assessment modeling is a modeling used in the issues that involves interaction of human and environment, such as climate change, land use change and water resources management. It is a combination of scientific knowledge, concerns of people, and policy preferences (Schlumpf et al., 1999). Other methods, such as scenario development and multi-criteria evaluation also have been conducted together with this integrated modeling. Participatory mapping and Geographical Information System are a participation-based modeling of spatial data and it is/has been particularly used in urban planning, landscape ecology, and environmental and natural resources studies.

2.5. Companion Modeling (ComMod)

2.5.1. Concept and process of Companion Modeling (ComMod)

Companion Modeling (ComMod) is one type of participatory models that is created to investigate complex natural resource management issues (Trébuil, 2008). The main principles of ComMod are to create simulation models represented the system of study based on various stakeholders’ perspectives and to support negotiation, collective learning and decision making (Barreteau et al., 2003) (Figure 2.4). An iterative process of ComMod between the model implementation and field study provides the better understanding of interaction between ecological and socioeconomic dynamics of the complex ecosystem. Therefore, ComMod approach can be used in two objectives: (1) to understand the complex environments by knowledge exchanging as well as co-learning, and (2) to improve a collective decision-making process (Barreteau et al., 2003).

The ComMod is the iterative and continuous process between laboratory and field activities. It is consisted of three main stages (Bousquet, Trébuil, and Hardy, 2005) (Figure 2.5):

(1) Field investigation and a literature search provide information and raise a set of key questions and hypotheses for modeling.
(2) Modeling is an alternation of existing knowledge into a formal tool to be used as a simulator.
(3) Simulation is conducted according to an experimental protocol in order to challenge the former understanding of the system and to identify new key questions for new focused investigation in the field.

In ComMod, the representation of social and ecological systems and knowledge sharing between stakeholders can be normally conducted by using game and simulation tools of agent-based models (ABM) and role-playing games (RPG) (Naivinit, 2008; Voinov and Bousquet, 2010).

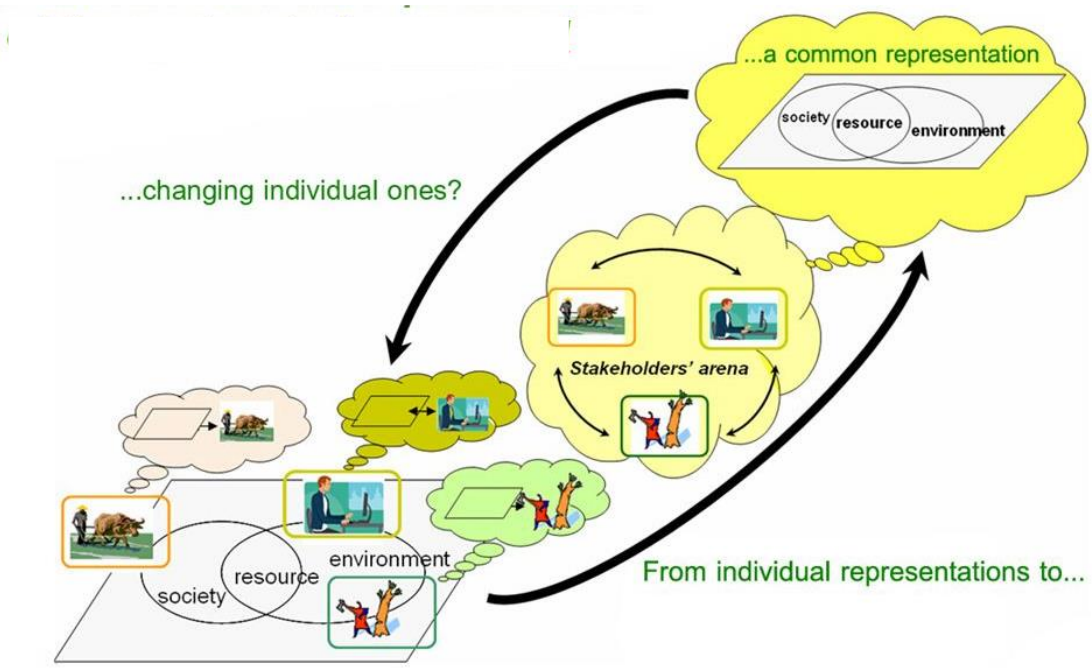


Figure 2.4 Schematic representation of a Companion Modeling process based on co-designing a shared representation among stakeholders
(Source: https://www.grease-network.org/teaching-training/vocational-trainings/2013/commod-workshop)

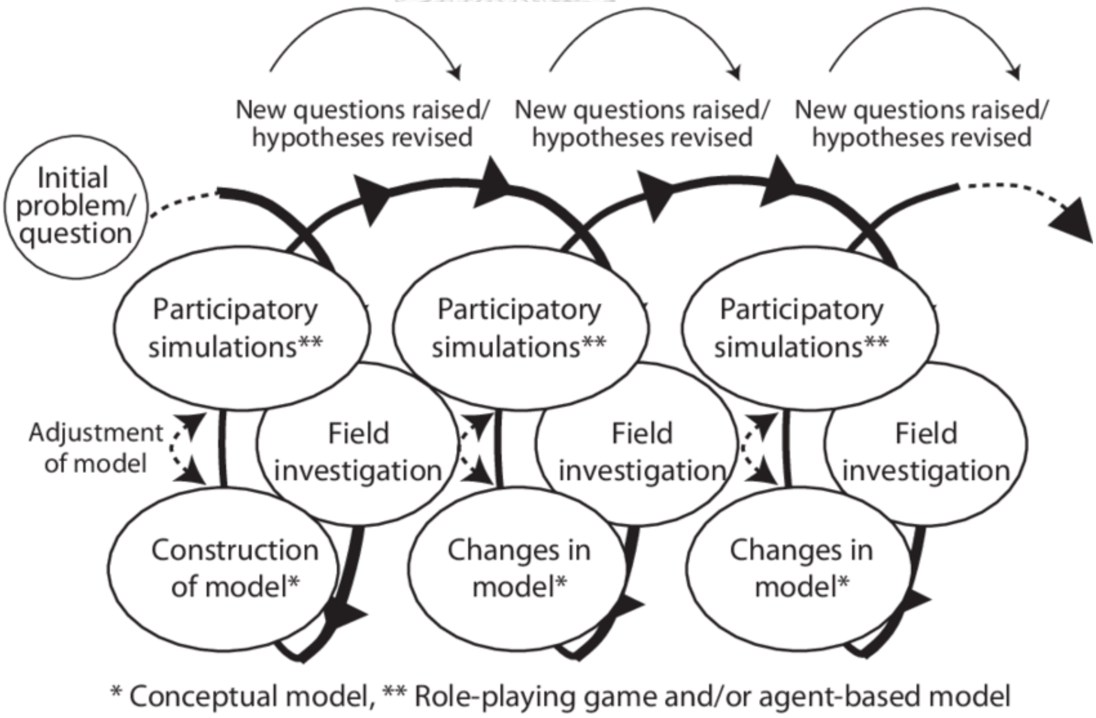


Figure 2.5 The iterative phases of a ComMod process
(Source: https://agritrop.cirad.fr/538649/)

ABMs are constructed based on computerized agents to represent the complex systems (Dumrongrojwatthana, 2009; Franziska and Ana, 2012). The bottom-up approach involves consideration of individual agents and comprehension of the emergence of system properties and the interaction among system agents (McLane et al., 2011). ABMs can provide portable, extensible, and transferable software and the game sessions can be repeated and stimulated by ABMs (Barreteau and Abrami, 2007; Macal and North, 2009). However, stakeholders can possibly experience ABM as black boxes due to a software or computer tool, and then it can result in the acceptability and legitimacy of model (Barreteau and Abrami, 2007).

RPGs are a simulation tool that presents the function of social systems and ecosystems and RPG can help knowledge sharing, collective learning, and decision-making support (Moreau, Barnaud, and Mathevet, 2019). According to Moreau et al. (2019), RPGs can contribute various social learnings, including raising the understanding and awareness of stakeholders on the interactions within systems, improving the capability for encountering the uncertainty, and discovering the innovative ways for management. Furthermore, RPGs are more similar to reality and can be used more easily than ABMs. RPGs are commonly used for encouraging engagement of participants in the model design (Naivinit, 2008). In addition, RPG can be used as a simplification of ABMs, therefore, more understandable by stakeholders (Barreteau and Abrami, 2007).

Nevertheless, a computer model can be used in gaming and simulation. Four types of computerized models have been proposed by Thavikulwat (2009) based on the relationship between the control of computer and the interaction of participant and computer. Computer-directed simulations are composed of high computer engagement and high computer-participant interaction, computer-based simulations are composed of high participant engagement and high computer-participant interaction, computer-controlled simulations are composed of high computer engagement and high participant-participant interaction, and computer-assisted simulations are composed of high participant engagement and high participant-participant interaction.

2.5.2. ComMod case studies

RPGs are widely used for various natural resource management situations. The use of RPG has promoted the participation among various levels of stakeholders and helped the participants to have more awareness of the issues related to natural resource management (Dumrongrojwatthana et al., 2007; Campo et al., 2009). Case studies using ComMod approach can be found at www.commod.org. The following are the case studies that used RPGs as learning tools in various ecosystems (Figure 2.6).

Abrami et al. (2012) created an RPG called Wat-A-Game for water management, policy design and education. The game was designed to be used by various types of stakeholders, including farmers, scientists, experts, administrators, and policy makers. The game could show the players how water moves within a landscape, how it is used, polluted, transformed and shared by actors and any trade-offs encountered. The game was used successfully for knowledge sharing and now it has been developed into other toolkits for case studies.

An RPG was also conducted for knowledge sharing and collective learning about soil management. Pruksakorn et al. (2018) developed “Soil Analysis and Appropriate Fertilizer Use game” to help farmers who have low-formal education to realize the soil analysis before planting and improving the appropriate chemical fertilizer usage. 3D game materials were used to represent the soil nutrients and fertilizers. In the step of game playing, the players had to analyze what soil nutrients did they have in their land box, then they would make decisions to buy fertilizer. After that, they had to harvest and sell their products. Learning occurred during debriefing by discussion and exchange knowledge and experiences among the players.

Joffre et al. (2015) created a 2D board game of “Coastal Aquaculture Spatial Solutions game” for improvement of understanding in shrimp aquaculture planning. The farmers were invited to the workshops. During game playing step, they had to make decisions on whether to retain or to change shrimp production system. After playing the game, the players found that this game is a good learning tool for assessing the risks involved in shrimp farming and for thinking about farm management.

a: Wat-A-Game (Source: https://nilebdc.org/2013/01/20/wat-a-game-fogera/)

b: Soil Analysis and Appropriate Fertilizer Use game (Source: https://journals.sagepub.com/doi/full/10.1177/1046878118759380)

c: Coastal Aquaculture Spatial Solutions game (Source: https://ars.els-cdn.com/content/image/1-s2.0-S0308521X15300378-gr5_lrg.jpg)

Figure 2.6 Example of Role-Playing Games under Companion Modeling Approach

CHAPTER III

MATERIALS AND METHODS

3.1. Assessment of green roof ecosystem services

3.1.1. Study sites

3.1.1.1. Study site survey and identification

Green roofs in Bangkok metropolitan area were surveyed and identified using the information from the Public Health and Environmental Strategy Division (Environment department of The Bangkok Metropolitan Administration, 2015). Inquiries were sent to the owners of 38 green roofs but, only seven green roofs allowed permissions to conduct research. The owners cited the concern about violation of customer or tenant privacy when they refused the research on their green roofs. The low permission response resulted in the small numbers of study sites. Therefore, the seven study sites were the green roofs on Aor Por Ror Building (APR), Anantara Siam Bangkok Hotel (ASH), Mahitaladhibesra Building (MHT), Mitkorn Mansion (MTK), Siam Green Sky (SGK), SG Tower Building (SGT), and the 60th Anniversary Building at Faculty of Veterinary Science (SXV) (Figure 3.1). The locations of the green roofs are shown in Figure 3.2. General information of each study site is presented in Appendix A.

(a) Aor Por Ror Building (APR)

(b) Anantara Siam Bangkok Hotel (ASH)

(c) Mahitaladhibesra Building (MHT)

(d) Mitkorn Mansion (MTK)

(e) Siam Green Sky (SGK)

(f) SG Tower Building (SGT)

(g) The 60th Anniversary Building at Faculty of Veterinary Science (SXV)

Figure 3.1 Seven green roof sites included in this study

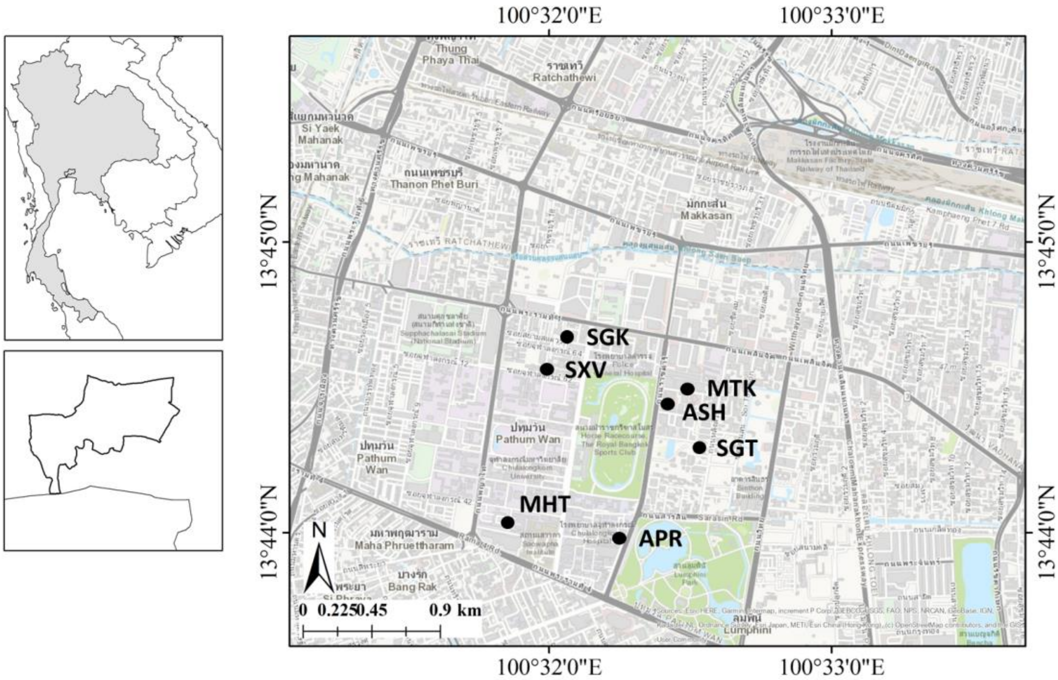


Figure 3.2 Location of the green roofs in Bangkok used in this study

(Source: https://www.google.co.th/maps)

3.1.1.2. General characteristics and plant information collection

The general characteristics of the green roofs are presented in Table 3.1. The building owners did not clearly identify the actual functions of the green roofs. Nevertheless, the intended functions could be indicated based on the utilization of each green roof as observed by the researcher during the data collection (Table 3.1). Green roof area was measured. Green roof vegetation was classified into plant types (trees, shrubs, herbs, and grasses) and the roof area for each plant type was measured (plant cover). In this study, the criteria used for vegetation classification was derived from the urban plant categorization by Davies et al. (2011) and the suitability for calculating aboveground carbon storage using allometric equations. Trees were defined as woody plants with a diameter at breast height (DBH) more than 4.5 cm; and palm trees were also included. Shrubs were defined as woody brushes with DBH less than 4.5 cm or an average height less than 2 m. Herbs meant non-woody plants and grasses. Design type of each green roof was also identified. A garden bed design was a green roof which vegetations were directly grown in a continuous coverage of substrate on the rooftops while a green roof which the installations of individual plants and substrate in containers were arranged on the rooftop surface was defined as a flowerpot design.

Table 3.1 General characteristics of the green roofs used in this study

Green roof study site	Building type	Height (m)	Total green roof area (m^2)	Plant form (T/S/H/G)*	Design type	Intended function
APR	Hospital	19.8	891	T/S/H/G	Garden bed	Recreation
ASH	Hotel	6.6	2,872	T/S/H/G	Garden bed	Recreation
MHT	University	16.5	287	T/S/H	Garden bed	Recreation
MTK	Condominium	6.6	942	T/S/H	Garden bed	Recreation
SGK	Department store	23.1	1,098	H/G	Garden bed	Education
SGT	Office	36.3	238	T/S/H	Flowerpot	Electrical equipment installation
SXV	University	29.7	1,159	T/S	Flowerpot	Recreation

Notes: *T, S, H, and G refer to trees, shrubs, herbs, and grasses, respectively.

3.1.2. Using direct methods for green roof ecosystem service assessment

3.1.2.1. Regulating services: Estimation of aboveground carbon storage

In this study, aboveground carbon storage was estimated separately for trees, palms, shrubs, herbs, and grasses on the green roofs between May 2016 – 2017. Diameter at breast height (DBH) and height (m) were measured for all trees present on each green roof. Allometric equations[1] specific to each tree species were considered firstly for calculation of aboveground biomass; however, if there was no tree species specific equation, the allometric equations specific to tree genus and family were considered, respectively. The allometric equation for evaluating aboveground biomass of tropical tree plantation (Banaticla, Come, and Lasco, 2007) were used instead if no allometric equations were available for individual species. The allometric equations used in this study are presented in Table 3.2. For palm trees, measurements included DBH (cm), basal diameter at 0.5 m above ground (BD) (BD would be collected if its DBH was less than 0.5 m), height (m.), and the number of fronds. Then, aboveground biomass of palms was calculated using the allometric equations proposed by Cole and Ewel (2006). Lastly, DBH of bamboos were measured, and then their aboveground biomass was estimated using the allometric equation proposed by Guomo et al. (2013).

Table 3.2 Allometric equations used for estimation of aboveground biomass of green roof tree species

Tree species	Allometric equation	References
Acacia auriculiformis	$AGB = \exp[0.4515(\ln DBH)-0.4573(\ln DBH)^2]$	Jayaraman, Muraleedharan, and Gnanaharan (1992)
Artabotrys siamensis	$AGB = 0.342 \times DBH^{2.073}$	Banaticla et al. (2007)
Cerbera odollam	$AGB = \exp[-2.289+2.649\ln(DBH)-0.021(\ln DBH)^2]$	Penman et al. (2003)
Dracaena loureiri	$AGB = 0.091 \times (DBH^{2.472})$	Kuyah et al. (2012)
Ficus annulata	$AGB = 0.1142 \times (DBH^{2.1148}) \times (H^{0.6131})$	Hung et al. (2012)
Ficus benjamina	$AGB = 0.1142 \times (DBH^{2.1148}) \times (H^{0.6131})$	Hung et al. (2012)
Millingtonia hortensis	$AGB = \exp[-2.289+2.649\ln(DBH)-0.021(\ln DBH)^2]$	Penman et al. (2003)
Mimusops elengi	$AGB = \exp[-2.289+2.649\ln(DBH)-0.021(\ln DBH)^2]$	Penman et al. (2003)
Moringa oleifera	$AGB = 0.342 \times DBH^{2.073}$	Banaticla et al. (2007)
Murraya paniculata	$AGB = 0.342 \times DBH^{2.073}$	Banaticla et al. (2007)
Plumeria rubra	$AGB = \exp[-2.289+2.649\ln(DBH)-0.021(\ln DBH)^2]$	Penman et al. (2003)
Polyalthia longifolia	$AGB = 0.342 \times DBH^{2.073}$	Banaticla et al. (2007)
Tabebuia aurea	$AGB = \exp[-2.289+2.649\ln(DBH)-0.021(\ln DBH)^2]$	Penman et al. (2003)
Wrightia religiosa	$AGB = \exp[-2.289+2.649\ln(DBH)-0.021(\ln DBH)^2]$	Penman et al. (2003)

Notes: AGB is Aboveground biomass (kg), DBH is diameter at breast height (cm), and H is tree height (m).

[1] Allometric equations are biomass estimation equations and have been based on diameter at breast height and height of vegetation.

The equations for palm aboveground biomass (Cole and Ewel, 2006) are as follows:

Stem biomass (y_{bole}) $= 0.0314 \times (DBH^2 \times H)^{0.9174}$ (kg); when DBH > 5 cm

$= 0.0486 \times (BD^2 \times H)^{0.6194}$ (kg); when DBH ≤ 5 cm

Leaf biomass (y_{leaf}) $= 0.0237 \times (DBH^2 \times H \times F)^{0.5121}$ (kg)

Rachis biomass (y_{rachis}) $= 0.0458 \times (DBH^2 \times H \times F)^{0.388}$ (kg)

Aboveground biomass of individual palm $= y_{bole} + y_{leaf} + y_{rachis}$ (kg)

Where DBH is diameter at breast height (cm), BD is basal diameter (0.5 m above ground), H is palm height (m), and F is the number of fronds.

The equation for bamboo aboveground biomass (Guomo et al., 2013) is as follows:

Aboveground biomass of bamboos $= 0.184DBH^{1.616}$ (kg)

Where DBH is diameter at breast height (cm).

To estimate shrub aboveground biomass, random sampling of four 1x1 m^2 quadrats were used. Height of shrubs (m.) was collected. Aboveground biomass of shrubs was calculated using the following equation by Davies et al. (2011):

Aboveground biomass of shrub $= 0.566(Height)^{2.315}$ (kg)

Then aboveground biomass of shrub in four sample quadrats was converted to total shrub aboveground biomass of a green roof.

Samples of herb and grass biomass were collected from four random samples of 10x10 cm^2 quadrats. The collected samples of herb and grass were oven-dried at 105˚C for 48 hours and the dry weight was measured. The dry weight of herbs and grass was then converted to total herb and shrub aboveground biomass of a green roof.

Then, aboveground carbon storage values of trees, palms, shrubs, herbs, and grasses were converted from the vegetation aboveground biomass using a 0.47 conversion factor (Penman et al., 2003).

3.1.2.2. Provisioning services: Investigation of species diversity and monetary values of edible and useful plants

Investigation of provisioning services on green roofs was conducted in January 2017. Plant species that could provide food and goods for provisioning services were identified and then classified into four types of use including edibles, ornamentals, medicinal, and other uses (i.e. timber, other non-timber uses) (Clarke et al., 2014). The identification and classification of utilization types of plants was conducted using concise encyclopedia of plants in Thailand, a database on Thai medicinal plants (PHARM database), a database on plants for landscape architecture, and a database on agricultural plants (Veesommai et al., 2008; Pooma, 2016; Medicinal Plants Information Center, 2017; Research University Network, 2017). Some plants could serve several use categories and then they were recorded for each category. Therefore, total number of species in all four provisioning services could be higher than total plant species. After that, plant species with provisioning service were examined using species composition in order to indicate dominant plant species in each use category. The following is the formula used for the species analysis.

Species composition using cover data (Launchbaugh, 2009)

$$\%\ \text{Composition of species A} = \left(\frac{\%\ \text{cov. of species A}}{\text{cov. for all species}}\right)$$

Where % Composition of species A = Percentage of species composition of plant species A
% cov. of species A = Percentage of cover area of plant species A
cov. for all species = Cover area of all plant species

The cost of a green roof installation and monetary benefits of the edible and ornamental plants uses were investigated. Due to lack of usable data, the installation cost of this study referred to only soft landscape of the green roofs. Thus, plant species and substrate (soil) area were recorded. The cost for installation of each green roof was composed of the cost of labor for installing and the cost of materials (plants and substrate) (Department of public works and town and country planning, 2012). The element costs in this study were derived from several sources including the actual cost for the green area installation project of Chulalongkorn University, medium-priced of plants, crops, and growing media proposed by the Environment Department of Bangkok Metropolitan Administration (BMA) and the Energy Regulatory Commission (Environment department of The Bangkok Metropolitan Administration, 2013; Energy Regulatory Commission, 2016), and the market average prices (Appendix B).

Because foods and goods on all green roofs in this study were not directly consumed or made direct income to the owners, the monetary benefits referred to the expected benefits in monetary values of the products from the edible plants and the prices of ornamental plants that green roof owners would obtain if the edible products and ornamental plants were sold. The monetary benefits of edible and ornamental plants on green roofs were estimated using the sale prices proposed by the Bureau of Agricultural Commodities Promotion and Management (2017) (Appendix C). The monetary benefits of some ornamental plant species were estimated using the same cost prices that used in the study of green roof installation cost because there were no sale prices proposed in the reference report. The medicinal and other use plants were not accounted for in the determination of monetary benefits of provisioning services due to low frequency and lack of available data.

3.1.2.3. Cultural services: Assessment of recreation and education benefits

Investigation of cultural services on green roofs was conducted in February 2017. Cultural services, including recreation and education benefits, were evaluated using the interviews and the observation of standards for recreation urban green space suggested by Office of Natural Resources and Environmental Policy and Planning (2014). The set of questions for semi-structure interview (Appendix D) was created based on Natural England's Standards for Accessible Natural Greenspace (ANGSt) (Natural England, 2010). It was composed of three standards: accessibility and quantity standards (i.e. accessibility and transport distances), service standards (i.e. installation of core services and facilities), and quality standards (i.e. quality of existing services and facilities). According to Natural England (2009), green roofs were classified as amenity greenspace[2]; therefore, the criteria for amenity greenspace were used in this study. Then, one person who was in charge of maintenance on each green roof was asked to participate in the interviews. However, the quality standards in ANGSt were the national quality standards of green space in England, namely the Green Flag Award scheme (Ellicott, 2016). Therefore, the standard for recreation urban green space developed by Natural Resources and Environmental Policy and Planning (Table 3.3) was applied and used as the quality standards of green space in Thailand. The standard evaluation was completed by observation and direct measurements. The results from the evaluation were performed in the number of achieved criteria of each green roof.

[2] Amenity greenspace is one type of green infrastructures and it can be informal recreation spaces, housing green spaces, domestic gardens, village greens, urban commons, other incidental space, or green roofs.

Table 3.3 Quality standards for cultural service assessment suggested by Office of Natural Resources and Environmental Policy and Planning (2014)

No.	Standards	Criteria
Quantity and accessibility standards		
1	Ratio of green area and population	0.8 m^2/ person
2	Size of green area	80-800 m^2
3	Number of people that can use the green area	Green area should provide the services for people who live about 300-500 m from their residence.
4	Accessibility	Everyone who is residents or officers of the buildings that have the green roof
Quality standards		
Sustainable green area		
5	Number of trees in sustainable green area	Number of trees (circumference more than 20 cm or DBH more than 6.37 cm.) should be more than 1 tree/100 m^2 of green area
Decreasing temperature		
6	Trees that provide shade for opened area	At least 1 tree/50 m^2 of opened area
Decreasing air pollution		
7	Decreasing CO_2	Decreasing more than 1.2 ton of CO_2/1600 m^2/year
Soil and water conservation		
8	Water-permeable area	Water-permeable area should be more than 75% of total area
Biodiversity		
9	Diversity of vegetation in green area	Number of plants in each species should be less than 5% of total number of plants.
10	Vertical vegetation	Proportion between tree cover and other plant types cover should be more than 50%.
Vegetation selection		
11	Suitable vegetation for ecology	At least 75% of total plant species are suitable species for ecology and planting area which should be native plant species or non-native plants that have the ability to adapt to environment and climate in Thailand.
12	Suitable vegetation for type of green area	At least 75% of total trees have medium or high potential in carbon sequestration.

3.1.2.4. Supporting services: Investigation of diversity in meso- and macro-soil fauna

Investigation of supporting services on green roofs was conducted in May 2016. Three 1x1 m2 quadrats on each study site were randomly selected. Biological data including percent of plant cover, weight of litter in random sampling plot were collected and physical data including soil pH, soil moisture, and temperature were also recorded. Meso- and macro- soil faunas were collected by hand collection, and then 20x20x5 cm3 of soil sample in each plot was collected. After that, soil faunas were extracted by using the Tullgren funnel method (Henderson and Southwood, 2016).

Soil fauna specimens were identified at an order level using Smithsonian Handbooks: Insects (McGavin, Sorkin, and Gorton, 2002). Soil fauna diversity were examined using Margalef index, Shannon-Wiener index, Simpson's Index of diversity and Sorensen's similarity coefficient calculated at the order level. The following are the formulas for the diversity indices used in this study.

(1) Richness index (Margalef, 1958)

$$R = \frac{(S-1)}{\ln(N)}$$

Where R = Richness index (Margalef index)

S = Number of orders in the sample

N = Total number of individuals in the sample

(2) Shannon-Wiener index (Shannon, 1948)

$$H' = -\sum_{i=1}^{k}(p_i)\,[\ln(p_i)]$$

Where H' = Shannon-Wiener index of order diversity

k = Number of orders in the sample

p_i= Proportion of total abundance represented by the i^{th} order

(3) Simpson's index of diversity (Simpson, 1949)

$$1 - D = 1 - \sum_{i=1}^{k}(p_i)^2$$

Where D = Simpson's index

k = Number of orders in the sample

p_i= Proportion of total abundance represented by the i^{th} order

(4) Sorensen's similarity coefficient (Sorensen, 1948)

$$S_S = \frac{2a}{2a+b+c}$$

Where S_S= Coefficient of similarity

a = Number of orders found in areas 1 and 2

b = Number of orders found in area 2 only

c = Number of orders found in area 1 only

All statistical analyses were performed using SPSS 22.0. The normality of the data was tested. Then, the collected data, including percent of plant cover, soil pH, temperature, weight of litter, and soil moisture were tested for correlations with Shannon-Wiener's index and Simpson's Index using Spearman rank-order correlation coefficient.

3.1.3. Using a rapid assessment checklist for green roof ecosystem service assessment

3.1.3.1. Construction of the rapid assessment checklist for assessment of green roof ecosystem services

A rapid assessment checklist for specifically evaluating ecosystem services provide by green roofs was developed using the methods in the ESC (Alam et al., 2016). Therefore, construction of the checklist tool was composed of five steps including defining the scope of the study, selecting the indicators, normalizing the variables, weighting the variables, and aggregating the normalized and weighted variables.

1. Defining the scope of the study

Based on the literature review, green roofs provided various environmental and social benefits that could be classified as ecosystem services. The following are ten green roof ecosystem services that were evaluated in this study: gas regulation, climate regulation, stormwater regulation, waste treatment, pollination, food provision, aesthetic information, recreation, education, and habitat function. These services could be classified into four categories of ecosystem services as shown in Table 3.4.

Table 3.4 Classification of ecosystem services on green roofs

Main ecosystem services categories	Services
Regulating services	Gas regulation
	Climate regulation
	Stormwater regulation and disturbance prevention
	Waste treatment (air pollution, water purification)
	Pollination
Provisioning services	Food provision
Cultural services	Aesthetic information
	Recreation
	Education
Supporting services	Habitat function

2. Selecting the indicators

Proxy indicators, which are the representative indicators of each ecosystem service, were used in this rapid assessment checklist. Ecosystem services can be estimated indirectly using the proxy indicators. The criteria for selecting the proxy indicators included involvement with green roofs, countability, availability, and information transferability (Alam et al., 2016). In addition, the literature review, the guidelines, and criteria in assessments of urban green spaces were also studied in order to select the indicators. Hence, 46 indicators were used in the rapid assessment checklist (Appendix E). The reference values were determined based on suggestions, assumptions, and expectations from various guidelines and research. The rapid assessment checklist is presented in Table 3.5. The checklist consisted of four indicator categories including green roof structure, physical factors, biological factors, and maintenance and management. In order to complete the checklist, answers to the yes/no questions, multiple-choice questions, and open questions were recorded and compiled.

Table 3.5 Rapid assessment checklist for green roof ecosystem services

Green roof structure	
Indicator	**Data**
Green roof types	❑ Intensive ❑ Extensive
Green roof area Percentage of green roof area in total floor area	________% *Green roof area:________m^2 Floor area________m^2
Green area of green roof	________m^2
Green roof height Floor that the green roof is located on	________level(s)
Substrate depth Garden bed: Depth of growing media layer Flowerpot: Average of soil depth in flowerpots	________cm.
Continuous coverage of substrate Percentage of area covered by substrate in green roof	________% *Green roof area________m^2 Substrate covered area________m^2
Drainage	❑ Yes ❑ No
Area exposed to sunlight Percentage of sunlight-exposed concrete area in total hardscape area	________% *Total hardscape area________m^2 Concrete area that exposed to sunlight m^2
Permeable surface area Percentage of permeable surface area in a green roof	________% *Green roof area________m^2 Permeable surface area________m^2
Storage reservoirs Existence of any water containers, e.g. bird baths and barrels, and ponds	❑ Yes ❑ No
Water sources E.g. ponds, swimming pools, basins, and water tap	❑ Yes ❑ No
Connectivity to natural habitat The near green area at ground level within a 200 m radius from the green roof	❑ Yes ❑ No
Physical factors	
Indicators	**Data**
Light soil	❑ Yes ❑ No
Soil pH	________(pH)
Undisturbed soil Opened area that is not disturbed by vegetation or any constructions	❑ Yes ❑ No
Topographic variation Provision of topographic variety E.g. sloped surfaces, different heights of garden beds, flowerpots, and edging	❑ Yes ❑ No
Nesting opportunities Provision of elements for nesting of birds and insects E.g. bare area, birdhouses, bee houses, tall shrubs, and branches	❑ Yes ❑ No
Perching habitat Provision of elements for attraction insects and birds to perch, e.g. branches, logs, and rocks	❑ Yes ❑ No
Sunlight hours on green roof	________Hours/day

Biological factors	
Indicators	**Data**
Major vegetation cover Majority of vegetation types that have the most percentage of plant cover in total green roof area	❑ Tree ❑ Shrub ❑ Herb ❑ Grass Tree cover:________% Shrub cover:________ % Herb cover:________% Grass cover:________%
Woody plants E.g. trees and shrubs	❑ Yes ❑ No
Vegetation species Majority of plant species that mostly found on the green roof	❑ Evergreen species ❑ Deciduous species
Planting systems	❑ Monoculture ❑ Polyculture
Phytoremediation potential of plant Existence of plants that have the ability to remove non-essential ions or toxic contaminants of green roof substrate	❑ Yes ❑ No
Flowering plants	❑ Yes ❑ No
Plants with seasonal variety	❑ Yes ❑ No
Plant species selection	❑ Exotic species ❑ Native species ❑ Both
Number of trees	________tree(s)
Number of plants that provide shade for the building in each building side	Length in each building side:________m. Number of plants in each building side tree(s)
Vertical structure of plants Percentage of tree covered area in total plant cover area	________%
Edible plants	❑ Yes ❑ No
Available crop yields	❑ Yes ❑ No
Crop damage by animals	❑ Yes ❑ No
Plant with long blooming season	❑ Yes ❑ No
Maintenance and management	
Indicators	**Data**
Fertilizer application	❑ Yes ❑ No
Pesticide used	❑ Yes ❑ No
Water access E.g. water tap	❑ Yes ❑ No
Drip irrigation system	❑ Yes ❑ No
Sun protection E.g. sunblock garden netting mesh	❑ Yes ❑ No
A wind breaker E.g. windbreak mesh	❑ Yes ❑ No
Messy appearance E.g. dirty, untidy, and abandoned area	❑ Yes ❑ No
Accessibility Permission to use green roof	❑ Yes ❑ No
Number of building visitors/customers	________person(s)/day
Facility for recreation E.g. chairs, tables, sunshades, footpath, lights, a swimming pool, and playground	❑ Yes ❑ No
Facility for education E.g. plant species labels	❑ Yes ❑ No
Education activities E.g. green roof tour or ecotourism	❑ Yes ❑ No

3. Normalizing the variables

The normalization was the step of transformation of multi-dimensional values to dimensionless values (Nardo et al., 2005). In this study, categorical scales and min-max were techniques used for normalizing variables. Then, each variable would be scored based on the level of relation between the recorded value and the reference values. About the categorical scale technique, the score of the variable in this checklist could be 0, 0.25, 0.5, or 1. For example, the reference values for carbon storage were indicated as one point for the existence of woody plants and 0.5 point for the disappearance of woody plants (Whittinghill et al., 2014). Therefore, the green roof with woody plants would gain one point whereas the green roof with herbs would receive 0.5 point.

4. Weighting the variables

The variables could be weighed differently depending on the importance of ecosystem service. However, each ecosystem service in this study was assumed that it had an equal importance; therefore, the variables were weighed equally. Weight of variables (w_i) was indicated by the following equation:

$$w_i = \frac{1}{ID}$$

Where w_i = weight of variables, which $\sum_{i=1}^{n} w_i = 1$ and $0 \leq w_i \leq 1$
ID = number of indicators in each service

5. Aggregating the normalized and weighted variables

Finally, the composite of ecosystem services was constructed based on the aggregation of the normalized and weighted variables using an arithmetic mean (Talukder, Hipel, and vanLoon, 2017). The following is the ESC formula used in this checklist tool:

$$ESC = \frac{\sum_{i=1}^{n} X_i w_i}{N}$$

Where X_i = normalized variables, w_i= weight of X_i, N = number of ecosystem services

3.1.3.2. Evaluation of green roof ecosystem services using the rapid assessment checklist

The rapid assessment checklist was tested and used for evaluating ecosystem services on seven selected green roofs during November 2016 – January 2017. Observations and direct measurements were conducted for recording the data of green roof structure, physical factors, and biological factors in the checklist. While observations and interviews with the green roof manager were used to complete maintenance and management data. The assessment was conducted by two users and each green roof required a half-day for the on-site checklist completion and an additional half-day for data processing and analysis.

The final results of the checklist were summarized as scores and radar charts. Scores were calculated for ecosystem service categories and then summed as a single value for total ecosystem service score for each green roof. The performance of the green roof in providing ecosystem services was then categorized from the score using interval width and four-point Likert scale interpretation (Brown, 2010). Four performance levels were proposed: poor (0-39), intermediate (40-59), good (60-79), and excellent (80-100), suggesting how a green roof was capable of providing ecosystem services. The definitions of performance levels are shown in Table 3.6.

Table 3.6 Assignment of performance levels of ecosystem service values

Performance level	Definition
Poor (Score: 0–39)	- Providing low ecosystem services - The indicators achieved less than 40% of the reference values, then the green roof lacks several desirable characteristics.
Intermediate (Score: 40–59)	- Providing moderate ecosystem services - The indicators achieved 40–59% of the reference values, then some of desirable characteristics are found.
Good (Score: 60–79)	- Providing generally high ecosystem services - The indicators achieved 60–79% of the reference values, then most of desirable characteristics are found.
Excellent (Score: 80–100)	- Providing high ecosystem services - The indicators achieved more than 80% of the reference values, then most or all of desirable characteristics are found.

Cluster analysis was used for classification of green roofs based on their total ecosystem service scores. The assumptions of Pearson correlation coefficient were checked. Then, the association among different ecosystem service scores which meet the assumptions was examined using Pearson analysis (i.e. regulating-cultural services, regulating-supporting services, and cultural-supporting services). Spearman rank-order correlation coefficient was used to test the correlation of provisioning-regulating services, provisioning-cultural services, and provisioning-supporting services. All statistical was analyses were performed using SPSS 22.0 program.

3.2. Perception of people on green roofs

3.2.1. Data collection

Perceptions on three aspects of green roofs in Bangkok including green roof utilization, priority of green roof ecosystem services, and decision for green roof construction, were collected using online questionnaires and semi-structure guideline for in-depth interviews. During April – June 2016, the online questionnaires (Appendix F) were uploaded as a google form and the link was sent to 349 respondents. The respondents could be divided into two groups of 259 university students and 90 workers.

The online survey were consisted of three parts: (i) six questions about general information of the respondents (i.e. gender, age, occupation, education level, income, and resident type), (ii) eight questions about the utilization of green roofs and the priority of green roof ecosystem services, and (iii) six questions about decision of green roof construction (Table 3.7). All data received from the survey were nominal data, except the priority of ecosystem services that was ordinal data. The priority of 10 ecosystem services (i.e. gas regulation, climate regulation, waste treatment, stormwater regulation, habitat function, recreation, pollination, aesthetic information, and food provision) were ranked based on how much is each service important for improvement of the urban environment in respondents' opinion. Then, the respondents were asked to give each service a score depending on the important level of the services (1-10 points; one point means the lowest importance and 10 points mean the highest importance). After that, the priority of ecosystem services in students' and workers' opinion were ranked separately using the average scores of each ecosystem services that gave by these two respondent groups.

Table 3.7 Example of the questionnaires used for investigating perception on the green roofs

Part II: Perception on the utilization of green roofs and the priority of green roof ecosystem services	Example of the questions: - Do you know a green roof? - What is the definition of the green roof? - In your opinion, what is/are the benefits from green roof implementation? - In your opinion, what is/are the disadvantage of green roof implementation?
Part III: Perception on decision of green roof construction	Example of the questions: - Do you need more the green roof at your university/workplace? - If you are the building owner (e.g. a department store, condominium, hotel, and office), do you want to construct the green roof at your building? - What support do you need for green roof construction?

In addition to online questionnaires, semi-structure interviews with participants who are working in urban environmental issues and other related fields were conducted. Five experts who have an experience in green roof design, construction, and management (three architects and one engineer) and have knowledge about urban ecosystem (one biologist) participated in the in-depth interviews in this study.

The semi-structure interview was composed of seven questions (Table 3.8) and each interview was conducted for at least 30 minutes. All data from the interview were descriptive information, except the priority of green roof ecosystem services that was ordinal data. The methodology for investigation of the priority of ecosystem services in the expert group was same as the study in the university student and worker groups.

Table 3.8 List of questions for semi-structure interview for investigating perception on green roofs

No.	Questions
1	What is the definition and general characteristics of a green roof?
2	How is the green roof recognized in the public?
3	What is the objective of green roof installation in Thailand?
4	Due to the potential of green roofs to provide ecosystem services, can you share your opinion on the uses of the green roof technology to solve the environmental problems in Bangkok?
5	Please give the following 10 green roof ecosystem services the scores (1-10 points) depending on your opinion about the important level of each service.

Ecosystem services	Scores (1=the lowest importance, 10=the highest importance)
Gas regulation	
Climate regulation	
Waste treatment	
Stormwater regulation	
Habitat function	
Recreation	
Pollination	
Aesthetic information	
Food provision	
Education	

No.	Questions
6	Is it necessary to include ecological knowledge in the green roof design?
7	Can you suggest the policies or incentives for encouraging people to construct the green roof?

3.2.2. Data analysis

The perception and priority of green roof ecosystem services in Bangkok were identified and analyzed using descriptive analysis. To evaluate whether the relationships between socioeconomic characteristics, including gender, age, education level, and income, and the interest of green roof construction, chi-square test was used. To analyze whether preferences for green roof ecosystem services differed between stakeholder groups, statistical analyses were performed independent samples t-test. All analyses were performed using the SPSS version 22.0 software.

3.3. Gaming and simulation for sharing knowledge about green roof ecosystem services

3.3.1. Objectives and scope of a participatory model

Gaming and simulation were conducted in order to share knowledge about green roof ecosystem services. The data from the previous investigations were prepared to use for creating two participatory models. The key information included preferable green roof characteristics for providing ecosystem services, qualitative and quantitative values of green roof ecosystem services, and perception on green roof ecosystem services. Therefore, two workshops were created for the different objectives. The first workshop was conducted for sharing knowledge about green roofs and ecosystem services on green roof to the students.

The second workshop was composed of two gaming sessions. The first gaming session was conducted for learning and sharing the green roof design based on ecosystem service knowledge to university students. The same objective was also indicated in the second gaming session but, instead of university students, the experts and other players who involved in green roofs and ecology participated in the second gaming session. In total, 18 gaming sessions were conducted for the first and second workshops (15 and 3 sessions, respectively). In order to achieve the objective of the second workshop, the capability of green roof composition for providing variety of ecosystem service types was needed to be emphasized. Then, the 2D game material was used instead of the 3D game material owing to higher complexity of the game in green roof design and calculation ecosystem service values. Summary of participatory models and gaming sessions is presented in Table 3.9.

Table 3.9 Summary of participatory models and gaming sessions

Characters	1st Workshop	2nd Workshop	
		1st Gaming session	2nd Gaming session
	(15–19 March 2017)	(5 and 7 November 2019)	(20 September 2019)
A participatory model	3D board game	2D board game	2D board game
Objective	Sharing knowledge of green roof ecosystem services	Sharing knowledge of designing ecosystem service based green roof	Sharing knowledge of designing ecosystem service based green roof
Participants	Students*	University students	Experts and other players

Note: *The passerby students who visited the Green Roof booth and were interested in playing the game

3.3.2. Creation of the conceptual models

Diagrams of two conceptual models were created using the Unified Modeling Language™ (UML®) program to present key actors, green roof elements, and the relationship that would happen in the game. Figure 3.3 and Figure 3.4 represent the conceptual models of the 3D green roof board game for the first workshop and the 2D green roof board game for the second workshop, respectively.

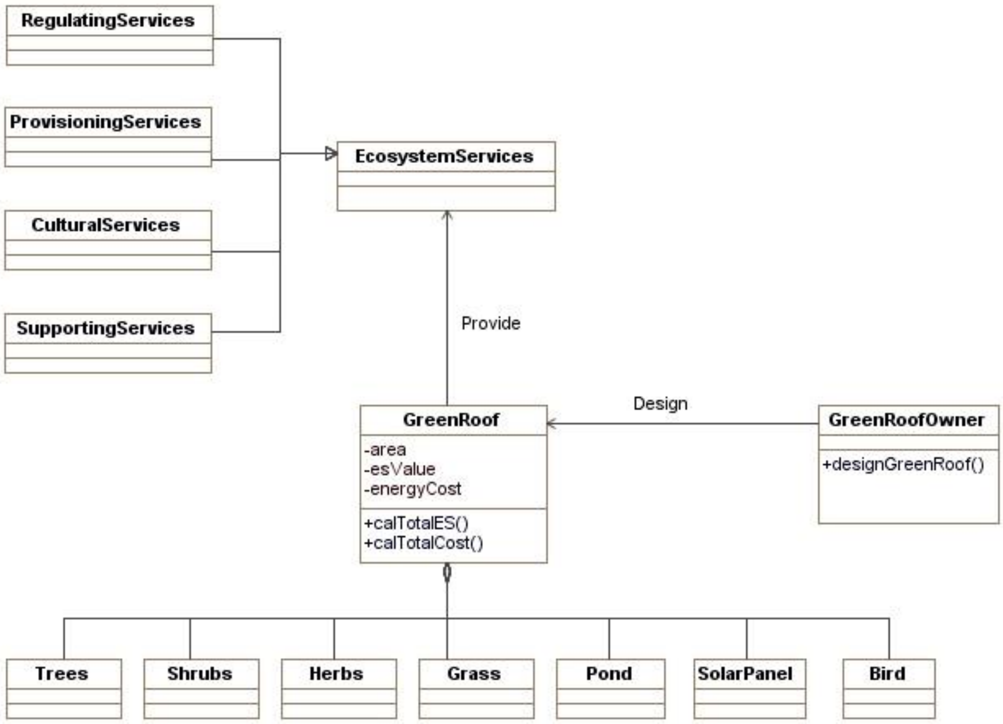


Figure 3.3 The conceptual model for the 3D green roof board game

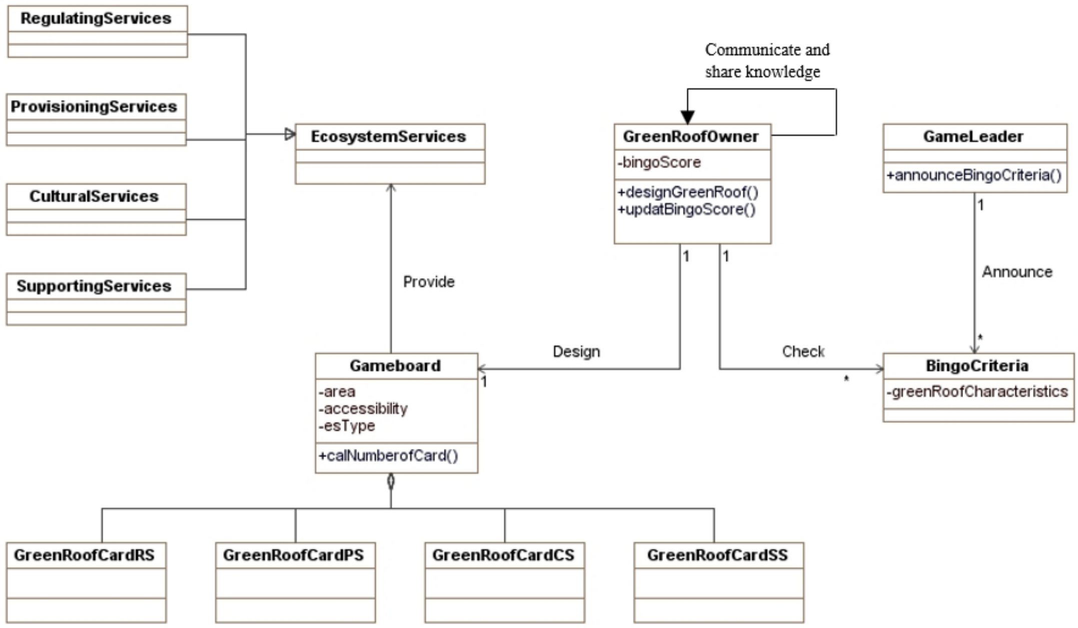


Figure 3.4 The conceptual model for the 2D green roof board game

3.3.3. Components and Procedures of green roof board games

3.3.3.1. Three-dimensional green roof board game (the first workshop)

Two versions of the 3D green roof board game were developed. The first version consisted of a game board and artifacts. The game board represent a bare rooftop and it composed of 10x15 cells (5 cm x 5 cm). The game artifacts or 3D-tokens represented green roof elements and ecosystem service points were indicated on each of the tokens. During the first version, the 3D-tokens of trees (coconut, and orange jessamine), shrubs (hibiscus), herb (cabbage), grass, pond, and solar panel were created and used (Figure 3.5). The second version was modified using the players' suggestions. Therefore, 3D-tokens of other herbs (aloe vera, African marigold, and rice) and several bird species were added to the second version (Figure 3.6).

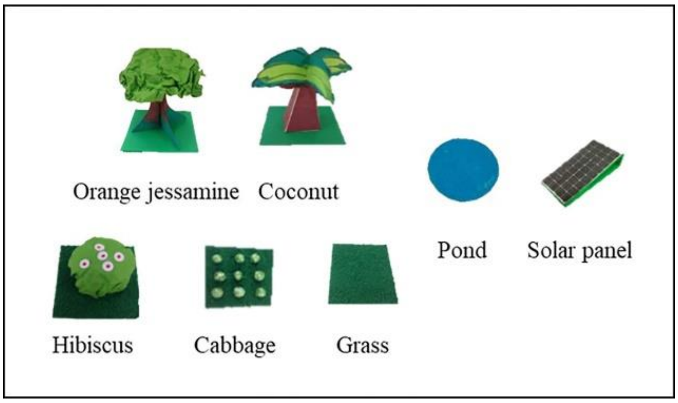


Figure 3.5 3D-tokens used in the first game version

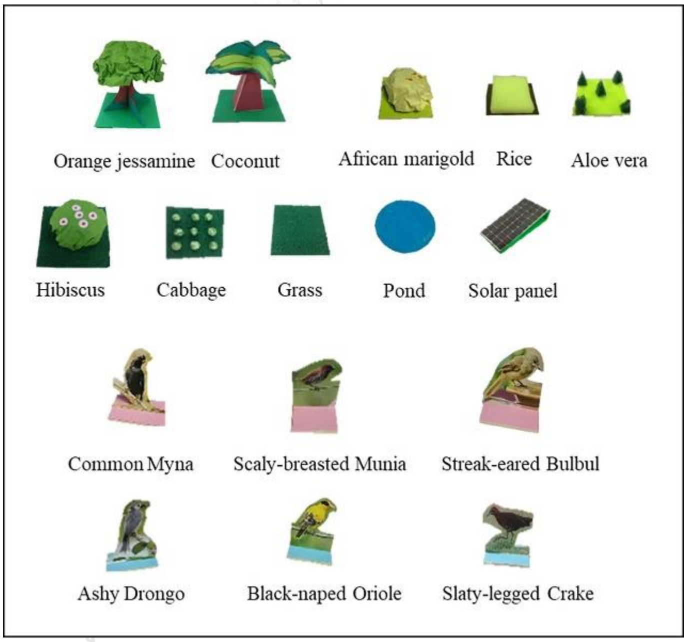


Figure 3.6 3D-tokens used in the second game version

Figure 3.7 describes the gaming steps of the first workshop. At the beginning of the game, the game moderator introduced the game and asked the players to answer the pretest about green roof knowledge (Table 3.10). Then, two groups of 4-6 players were asked to design and construct their own green roof in five minutes using the provided artifacts. After that, the players were asked to calculate the ecosystem service scores of four main categories, including regulating, provisioning, cultural, and supporting services. Then, the posttests were completed by the players. A debriefing was conducted by sharing and discussing their concepts and ideas used in their green roof design and construction as well as the ecosystem services provided by their green roofs. Lastly, a survey for game collective learning assessment was completed by the players to evaluate the satisfaction of the activity, indicate strong and weak points of the game, and give the suggestion for improvement of the game and further workshop (Table 3.11).

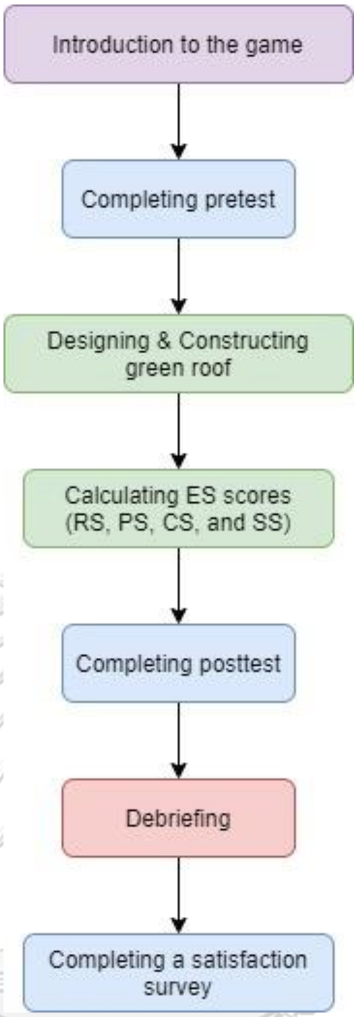


Figure 3.7 Procedures to play the 3D green roof board game

Table 3.10 Pretest and posttest questions for evaluation of collective learning

No.	Green roofs characters	Yes	No
1	Green roofs are only rooftop with installation of growing media and plants.		
2	Ratio of green space area per person in Thailand is similar to the international standard.		
3	Green roofs can provide 4 benefits including global warming mitigation, scenery provision, habitat provision, and product provision.		
4	Green roofs can help to decrease building temperature and air pollution.		
5	Green roofs can play the role as habitat for some resident birds.		
6	Scenery on green roofs can be used to attract tourism and to be learning center.		
7	Diversity of plants on green roofs can help to provides habitat for several animals.		
8	Green roofs can increase wastewater of the building.		
9	Green roofs are suitable for growing small flowers.		
10	Green roofs are the alternative way for increasing green space in urban area.		

Table 3.11 Assessment for game collective learning and workshop satisfaction

No	Criterion: Ability of board game for collective learning	Score				
		1 Very poor	2 Poor	3 Average	4 Good	5 Excellent
1	Playing the game helps me to understand more about green roof benefits.					
2	The game is easy to play and is not complex					
3	Playing the game makes me want to increase green space at my residence.					
4	I want to transfer the knowledge from this game to other people if I have a chance.					
5	Game atmosphere is fun and is not stress					
6	Staff are friendly					
No	**Criterion: Satisfaction of participants in the game equipment and process**	**Too small/little**		**Suitable**		**Too large/much**
1	Size of board game					
2	Number of plant species for tokens					
3	Number of plant tokens					
4	The given time for creating own green roof					
5	The given time for debriefing and conclusion					
6	The given time for overall of game session					

3.3.3.2. Two-dimensional green roof board game (the second workshop)

The 2D green roof board game consisted of a game board, green roof cards, bingo scorecards, 25 alphabet cards with bingo criteria, and other recording sheets. The game board was composed of 5 rows and 5 columns of 6 cm × 6 cm cells (Figure 3.8), representing a bare rooftop of 900 m^2, which is the average area of the green roofs in this study. The green roof cards represented green roof elements including vegetation, substrate, and other facilities (Figure 3.9). Different green roof cards showed different composition of green roof elements, such as species and types of plants, types of substrate, facilities, and other additional elements (e.g. solar cells, bird bath, and bird feeder). Necessary information of used components in 20 different green roof cards was provided to the players. The players could use the information to make a decision for their green roof design. In addition, all green roof cards were intentionally designed by the researcher to provide different ecosystem services. Therefore, the cards could be divided into five types based on the potential to serve ecosystem services, including regulating, provisioning, cultural, and supporting services and bare area that had lower ecosystem services. However, this attribute was not revealed to the players. The bingo scorecards consisted of 25 squares with random alphabets (A to Y). The same 25 alphabets were used to create alphabet cards. Each alphabet card contained a different criterion about preferable characteristics and elements of green roofs that possibly help to enhance ecosystem services (Appendix G). These alphabet cards were used during the bingo part of the game. Other recording sheets were generated in online platform using google forms. They included data record sheets for the first and second scenarios, rapid assessment for green roof ecosystem services (Appendix H), pretest and posttest about green roof knowledge (Table 3.12), and activity satisfaction survey (Table 3.13).

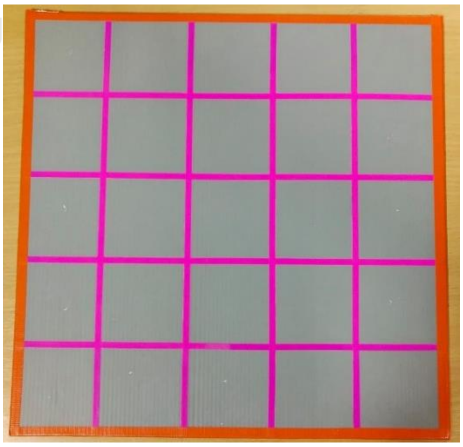


Figure 3.8 The game board represented bare rooftop

Figure 3.9 Example of green roof cards represented green roof elements

Table 3.12 Pretest and posttest questions for evaluation of collective learning

No.	Green roof characters	Yes	No
1	A green roof is a rooftop with a green color.		
2	A green roof is a rooftop designed in order to save building energy and reduce environmental problems. It can be classified as green architecture, clean architecture, or clean technology)		
3	A green roof is growing vegetation on a rooftop or using plants with flowerpots to decorate on a rooftop or balcony.		
4	Green roof technology cannot be found in Thailand.		
5	Green roof technology is one of the strategies for increasing green space in urban areas.		
6	A green roof can help reduce carbon dioxide in the atmosphere and also decrease building temperature.		
7	A green roof can help conserve several plant and fauna species in the urban areas.		
8	A green roof can be used as a food source or agricultural area in the urban ecosystem.		
9	A green roof provides aesthetic values and can be used as a recreational area.		
10	People can use a green roof as an educational area.		
11	Due to the limitations of green roof structure, the vegetation cannot be planted diversely, then the diversity of vegetation on a green roof are usually low.		
12	A green roof should not be opened for the public because of safety concerns.		
13	Plants that provided environmental benefits (e.g. high potential in carbon storage or air pollution control) should be selected and used on a green roof.		
14	Crops (e.g. vegetables or fruits) can be grown on a green roof.		
15	Plants that grown in flowerpots provided higher environmental benefits than plants that grown directly on a continuous substrate.		

Table 3.13 Survey for workshop satisfaction

No.	Criteria	Satisfaction				
		1 Very poor	2 Poor	3 Average	4 Good	5 Excellent
1	The green roof game is interesting.					
2	The game is easy to play and is not complex.					
3	The materials and tools of the game are suitable.					
4	The time used for playing the game is suitable.					
5	You gained more knowledge about a green roof.					
6	You have learnt more about benefits provided by a green roof.					
7	You have learnt about designing a green roof in an ecology aspect.					
8	The game atmosphere is fun and is not stress.					
9	Staffs are friendly.					
10	This game can be used as a tool for transferring the knowledge about a green roof to the public.					
11	Playing game raises your awareness of the importance of green roof design in an ecology aspect.					
12	You think ecology knowledge should be included in designing a green roof.					

Each game session was divided into two scenarios. The first scenario allowed the players to design and create green roofs freely depending on their own objectives. Figure 3.10 presents the gaming steps of the second workshop. To start the game, the game moderator introduced the game and asked the players to answer the pretest. Then, the players were separated into groups, each with up to 12 players. Each group then receive one green roof game board which is shared among all players. The players played the role as building owners who want to build the green roof on their buildings. Then, they were given 15 minutes to design and construct their own green roof using the green roof cards. During the next part of the game, each group received the bingo scoreboard. When the game moderator picked one alphabet card randomly and read its criterion, the players checked their green roof characteristics and elements against the criterion. If their green roofs could achieve the criterion, the players could write a cross symbol (X) on that alphabet square in their bingo scoreboard. The players were also asked to note the total number of achieved criteria. The bingo part was continued with the same procedures until some groups got five cross symbols on squares in a horizontal, vertical, or diagonal row. Then, the group that got a bingo would receive extra scores for two points. Therefore, the total scores of the game came from (1) total number of achieved criteria and (2) extra two points from getting the bingo. The winner of the first scenarios would be the group that have the highest total scores. After that, each group were asked to complete the data record sheets for the first scenario.

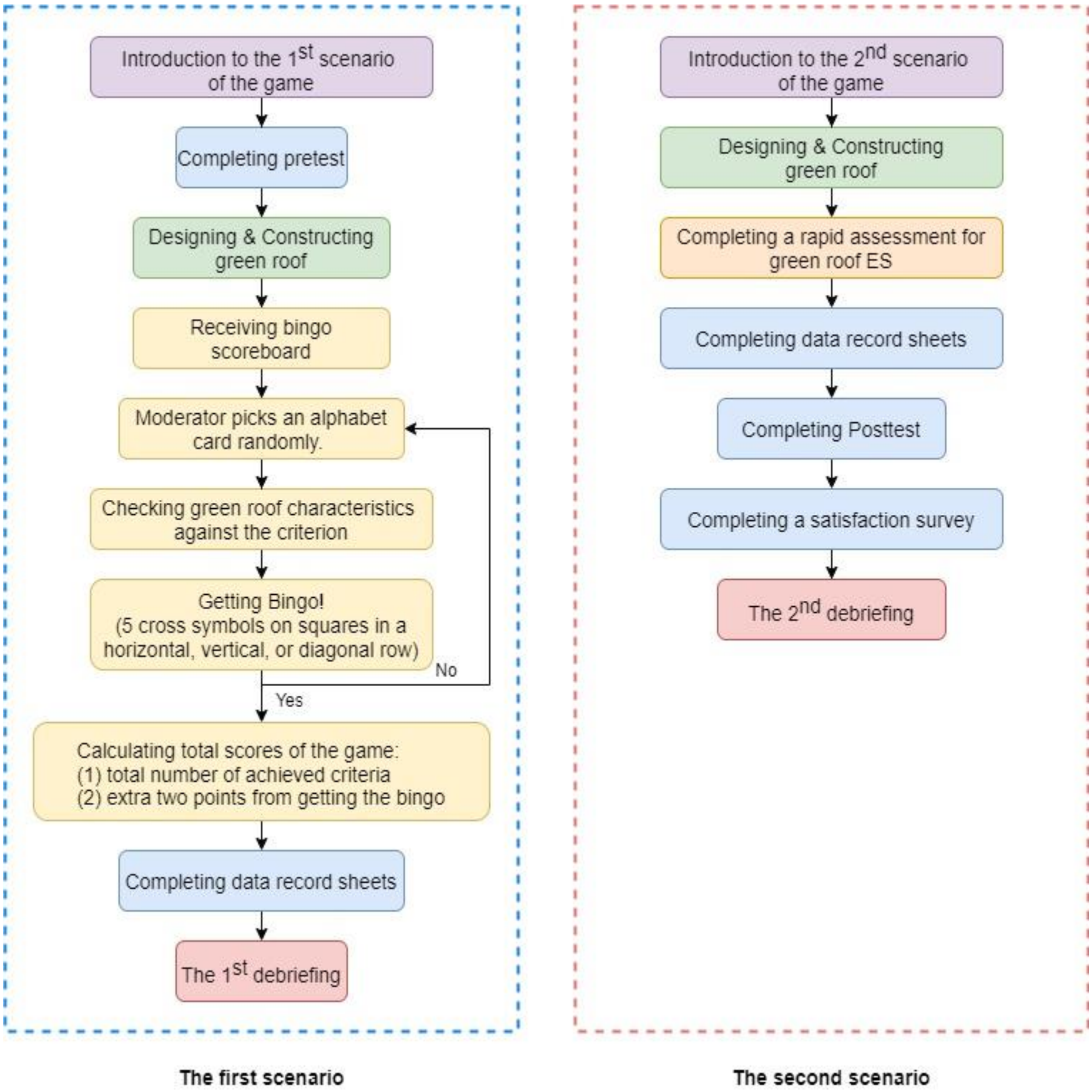


Figure 3.10 Procedures to play the 2D green roof board game

During the second scenario, the objective was to construct a green roof that would enhance ecosystem services. The players then repeated the same game steps as in the first scenario. Specifically, the players designed and created their green roofs using the green roof cards in a period of 15 minutes. Then, each group was asked to do the rapid assessment for green roof ecosystem services and the data record sheets for the second scenario.

Debriefing sessions were conducted in both scenarios. The players presented their constructed green roofs and exchanged the concepts used for their green roof design and green roof card selection. Moreover, the ecosystem services provided by green roofs and the preferable green roof characters and elements in an ecosystem service aspect were also discussed. Thereafter, the players completed posttest and activity satisfaction survey.

3.3.4. Implementation of the model

3.3.4.1. Three-dimensional green roof board game (The first workshop)

The first workshop using the 3D green roof board game was conducted during "Chulalongkorn University Academic Expo" on 15-19 March 2017. A total of 285 secondary school students participated in the workshop. They were composed of 148 and 137 players of the first and the second game versions, respectively.

3.3.4.2. Two-dimensional green roof board game (The second workshop)

The 2D green roof board game was played during two game sessions in 2019. The first game session was implemented on 5 and 7 November 2019 with 159 university students in Faculty of Science (i.e. Department of Biology, Botany, Environmental Science, and Marine Science) and Faculty of Education (Secondary Education (Science)), Chulalongkorn University. They were divided into 15 groups. On 20 September 2019, the second game session was conducted with five experts and other participants of Chulalongkorn University who involved or have experienced in working on green roofs or any urban green spaces projects. The following are the participants of this game session: a landscape architect, an engineer, a representative from the Office of Physical Resources Management of Chulalongkorn University, a representative from the Office of Property Management of Chulalongkorn University, and a graduate student from Chulalongkorn University who was conducting a research on bird diversity in urban parks of Bangkok. Thus, each of these five players played the game individually. Each game session was conducted for three hours.

3.3.5. Data analysis

The results of learning green roofs and their ecosystem services from the game were analyzed using a paired t-test. The results from the satisfaction survey of the activities were analyzed using a descriptive analysis.

All analyses were performed using SPSS version 22.0.

CHAPTER IV

DIRECT ASSESSMENT OF GREEN ROOF ECOSYSTEM SERVICES

4.1. Characteristics of study roofs

Seven green roofs in Bangkok were included as study sites. Five green roofs, specifically APR, ASH, MTK, MHT, and SXV, were installed for recreation purposes. SGK was used for urban agricultural education with workshops/sessions aimed to teach the public about farming, crop cultivation, food production and safety processes, and urban food security. The rooftop area of SGT was used for installation of electrical equipment, including antennas and air conditioner units. The five recreational green roofs were open to visitors during the office hours of 6:00 am to 8:00 pm. Access to SGK was allowed occasionally when there were educational activities. The public access of SGT was restricted, then people could not use the green roof.

All green roofs were classified as the intensive type but with different designs. APR, ASH, MHT, MTK, and SGK were of the garden bed design, in which plants were directly grown in a continuous coverage of substrate on the rooftops. SXV and SGT were of the flowerpot design, in which individual plants and their substrate were installed in containers which were arranged on the rooftop surface.

MHT provided the highest proportion of green area (66%) whereas the lowest green area proportion (2%) was found on SXV. APR and ASH were the only green roofs with all plant growth forms (trees, shrubs, herbs, and grasses) and so they provided the highest variety of vegetation growth forms. All green roofs, except SGK, contained trees and shrubs. Herbs were found in all green roofs except SXV. Grasses were present on only APR, ASH, and SGK. In terms of plant abundance, the highest number of shrubs and total plants was observed on MTK, while ASH had the highest number of trees as well as number of tree species and all plant species. The APR rooftop had the greatest number of shrub species. Plants found on the study sites were commonly used species in landscape design for aesthetic and recreation. The exception was the plant species on SGK, which were mostly crops, such as *Ocimum tenuiflorum* and *Ocimum basilicum*.

4.2. Plant species diversity

A total of 77 plant species were found on all green roofs in this study, including 25 tree, 24 shrub, 27 herb, and 4 grass species (Figure 4.1 and 4.2, Table 4.1, and Appendix I). Three species could be classified into either tree or shrub species depending on their sizes, namely *Acacia auriculiformis*, *Murraya paniculata*, and *Wrightia religiosa*. Among tree species found on the green roofs, *Bambusa multiplex* showed the highest abundance (31%), followed by *Dypsis lutescens* (16%), *Ptychosperma macarthurii* (11%), *Rhapis excelsa* (7%), *Cocos nucifera* (4%), and *Murraya paniculata* (4%), respectively (Figure 4.3).

Five shrub species most abundantly found on the green roofs were *Ixora chinensis*, with the highest abundance (38%), followed by *Bougainvillea spectabilis* (15%), *Ixora macrothyrsa* (11%), *Ehretia microphylla* (9%), and *Ficus* sp. (6%), respectively (Figure 4.4).

The most abundant herbs included *Axonopus compressus* with the highest abundance (28%), *Epipremnum aureum* (16%), *Ocimum tenuiflorum* (13%), *Ocimum × africanum* (11%), and *Hymenocallis littoralis* (6%), respectively (Figure 4.5).

(a) (b) (c)

Figure 4.1 Example of plant species found on the green roofs in this study: (a) *Bambusa multiplex*, (b) *Ixora chinensis*, and (c) *Chrysopogon zizanioides*

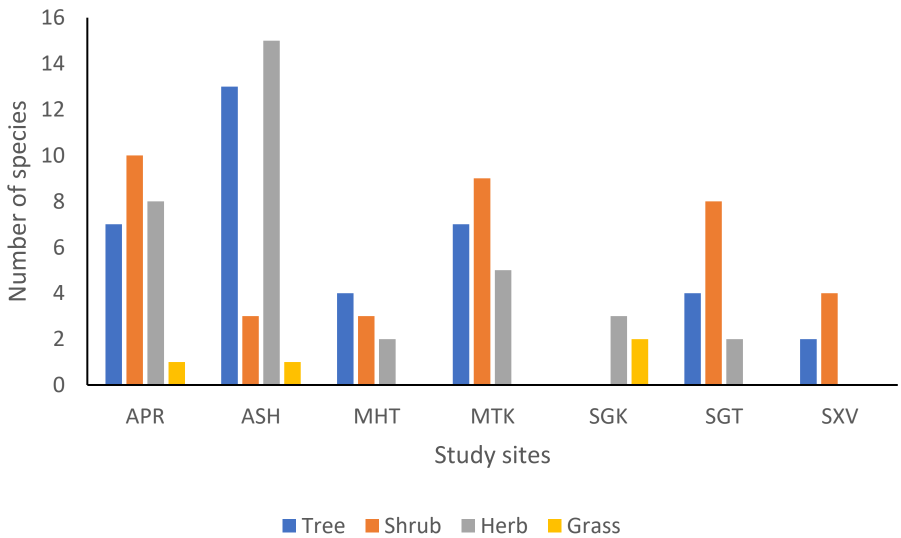


Figure 4.2 Number of plant species on each green roof separated into plant growth forms

Table 4.1 Vegetation species found on seven green roofs

Plant type	Scientific name	Thai name	Green roof sites						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
Tree	*Acacia auriculiformis*	กระถินณรงค์		✓				✓	
	Adonidia merrillii	หมากนวล	✓						
	Artabotrys siamensis	การเวก		✓					✓
	Bambusa multiplex	ไผ่เลี้ยง		✓		✓			
	Caryota urens	เต่าร้าง		✓					
	Cerbera odollam	ตีนเป็ดน้ำ	✓						
	Cocos nucifera	มะพร้าว		✓					
	Copernicia prunifera	ปาล์มแว็กซ์				✓			
	Dracaena cochinchinensis	จันทน์ผา		✓		✓			
	Dypsis lutescens	หมากเหลือง		✓				✓	
	Ficus annulata	ไทรอินโด				✓			
	Ficus benjamina	ไทรย้อยใบแหลม	✓	✓				✓	
	Millingtonia hortensis	ปีบ			✓				
	Mimusops elengi	พิกุล				✓			
	Moringa oleifera	มะรุม	✓						
	Murraya paniculata	แก้ว	✓						
	Plumeria rubra	ลั่นทม	✓		✓	✓		✓	
	Polyalthia longifolia	อโศกอินเดีย		✓					
	Pritchardia pacifica	ปาล์มพัด		✓					
	Ptychosperma macarthurii	หมากเขียว		✓	✓				✓
	Rhapis excelsa	จั๋ง		✓					
	Tabebuia aurea	เหลืองปรีดียาธร			✓				
	Thrinax parviflora	ปาล์มสะคือเขียว		✓					
	Wodyetia bifurcate	ปาล์มหางกระรอก				✓			
	Wrightia religiosa	โมกบ้าน	✓						

Table 4.1 (continued)

Plant type	Scientific name	Thai name	Green roof sites						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
Shrub	*Acacia auriculiformis*	กระถินณรงค์						✓	
	Bougainvillea spectabilis	เฟื่องฟ้า	✓			✓		✓	✓
	Codiaeum variegatum	โกสน	✓						
	Cordyline fruticosa	หมากผู้หมากเมีย		✓					
	Duranta erecta	เทียนทอง				✓			
	Ehretia microphylla	ชาฮกเกี้ยน				✓			
	Euphorbia pulcherrima	คริสมาสต์	✓						
	Ficus microcarpa	ไทรทอง				✓			
	Ficus sp.	ไทรเกาหลี				✓		✓	✓
	Gardenia jasminoides	พุดศุภโชค	✓			✓			
	Graptophyllum pictum	ใบทอง			✓				
	Hibiscus spp.	ชบา	✓						
	Ixora chinensis	เข็มญี่ปุ่น	✓		✓	✓			
	Ixora finlaysoniana	เข็มพวงขาว		✓					
	Ixora longifolia	เข็มเศรษฐีมาเลเซีย	✓					✓	
	Ixora macrothyrsa	เข็มเศรษฐี	✓			✓		✓	
	Mangifera indica	มะม่วง						✓	
	Murraya paniculata	แก้ว						✓	
	Pisonia grandis	แสงจันทร์						✓	✓
	Pseuderanthemum carruthersii	ใบนาค			✓				
	Pseuderanthemum crenulatum	เข็มม่วง	✓						
	Rhapis excelsa	จั๋ง		✓					
	Tabernaemontana pandacaqui	พุดร้อยมาลัย	✓						
	Wrightia religiosa	โมกบ้าน		✓		✓			✓

Table 4.1 (continued)

Plant type	Scientific name	Thai name	Green roof sites						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
Herb	*Aechmea fasciata*	สับปะรดสี		✓					
	Aerva sanguinolenta	แดงชาลี		✓					
	Alocasia macrorrhizos	กระดาด	✓						
	Asplenium nidus	เฟิร์นข้าหลวง		✓					
	Asystasia gangetica	บุษบาริมทาง ใบต่าง		✓					
	Axonopus compressus	หญ้ามาเลเซีย		✓					
	Callisia fragrans	ควนอิมพันมือ	✓						
	Cheilocostus speciosus	เอื้องอินโด		✓					
	Chlorophytum laxum	เศรษฐีเรือนนอก		✓					
	Chrysopogon zizanioides	หญ้าแฝก					✓		
	Clitoria ternatea	อัญชัน	✓						
	Cynodon dactylon	หญ้าเบอร์มิวดา	✓						
	Dieffenbachia seguine	ช้างเผือก	✓						
	Dracaena surculosa	ไผ่ฟิลิปปินส์		✓					
	Epipremnum aureum	พลูด่าง		✓		✓			
	Ficus pumila	ตีนตุ๊กแก				✓			
	Heliconia spp.	ธรรมรักษา ก้ามกุ้ง		✓					
	Homalomena rubescens	ว่านเสน่ห์จันทร์แดง	✓						
	Hymenocallis littoralis	พลับพลึงตีนเป็ด	✓	✓	✓			✓	
	Nephrolepis cordifolia	เฟิร์นใบมะขาม		✓					
	Ocimum × africanum	แมงลัก					✓		
	Ocimum basilicum	โหระพา					✓		
	Ocimum tenuiflorum	กะเพรา					✓		
	Pandanus amaryllifolius	เตยหอม					✓		
	Pandanus tectorius	การะเกด		✓					

Table 4.1 (continued)

Plant type	Scientific name	Thai name	Green roof sites						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Philodendron Xanadu	ซานาดู	✓						
	Phymatosorus scolopendria	เฟิร์นหลังลวน		✓	✓	✓			
	Ruellia squarrosa	ต้อยติ่งฝรั่ง	✓	✓		✓			
	Sansevieria spp.	ลิ้นมังกร		✓					
	Spathiphyllum spp.	เดหลี				✓			
	Sphagneticola trilobata	กระดุมทอง						✓	

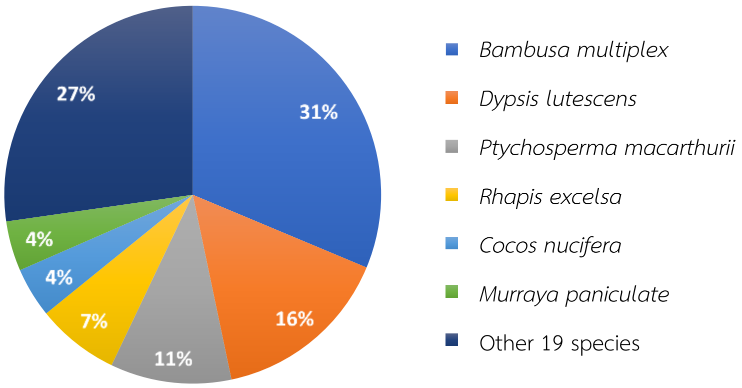


Figure 4.3 Relative abundance of tree species found on seven green roofs in this study

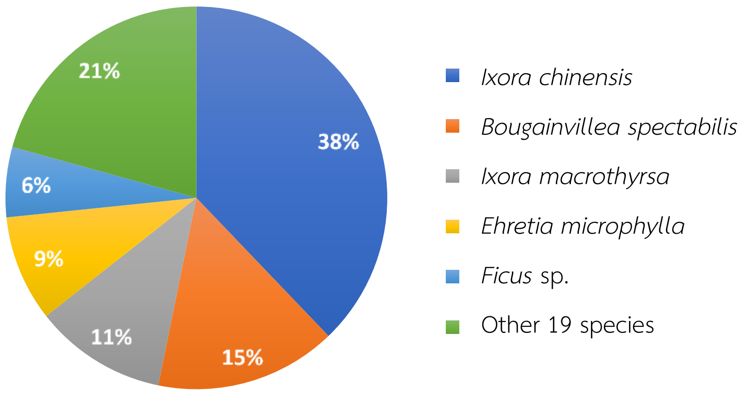


Figure 4.4 Relative abundance of shrub species found on seven green roofs in this study

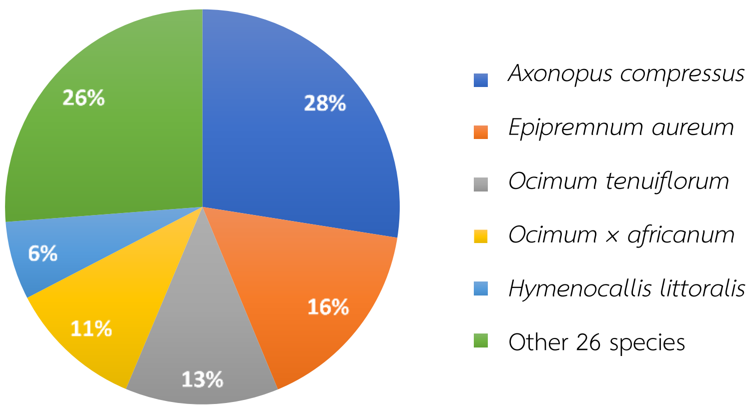


Figure 4.5 Relative abundance of herb species found on seven green roofs in this study

4.3. Potential of green roofs to provide ecosystem system services

4.3.1. Regulating services: Amount of aboveground carbon storage between May 2016 – 2017

An average carbon storage of 2597.89±3831.85 kg was found across the selected green roofs in this study (Table 4.2). In 2016, the highest amount of 10612.85 kg was calculated from the vegetation on ASH while the lowest amount of 57.38 kg was observed on SGT. Most of the carbon storage on most green roofs was derived from trees except on SGK where the carbon storage mostly came from herbs. When carbon storage was divided among the plant growth forms, the average carbon storage amounts from trees, shrubs, and herbs were 2422.95, 85.95, and 89.00 kg, respectively. ASH provided the highest amounts of tree and herb carbon storage of 10178.11 and 392.01 kg, respectively. MTK stored the highest amount of 293.51 kg shrub carbon storage. On the other hand, SGT stored the lowest amount of carbon from trees, shrubs, and herbs (Table 4.2). Surprisingly, the amount of carbon storage per unit area of MHT (15.06 kg/m^2) was considerably higher than ASH (3.70 kg/m^2) (Table 4.3). SGT and SXV provided the similar amount of carbon storage per unit green roof area (0.24 and 0.25 kg/m^2, respectively) although SGT had a much lower amount of total carbon storage than SXV.

Table 4.2 Total aboveground carbon storage on the green roofs measured in 2016 and 2017

Study sites	Plant cover (%)			Amount of total carbon storage measured (kg.)							
	Tree	Shrub	Herb	2016				2017			
				Tree	Shrub	Herb	Total	Tree	Shrub	Herb	Total
APR	62	23	15	1128.39	70.89	80.09	1279.36	1151.57	79.43	82.48	1313.48
ASH	74	10	16	10178.11	42.73	392.01	10612.85	10298.51	44.68	406.74	10749.93
MHT	72	14	14	4157.5	151.27	19.13	4327.91	4254.79	148.41	22.19	4425.39
MTK	58	29	12	1194.79	293.51	8.24	1496.54	1254.44	298.79	10.44	1563.66
SGK	0	0	100	0	0	121.46	121.46	0	0	0	0
SGT	26	65	9	40.5	14.85	2.04	57.38	30.75	17.62	2.08	50.45
SXV	89	11	0	261.37	28.38	0	289.75	311.74	26.72	0	338.46
Average	54	22	24	2422.95	85.95	89	2597.89	2471.69	87.95	74.85	2634.48
SD	31	21	34	3709.33	104.24	141.32	3831.85	3750.46	105.26	149.24	3891.21

Table 4.3 Amount of aboveground carbon storage per unit area of green roof measured in 2016 and 2017

Study sites	Plant cover (%)			Amount of carbon storage per unit area of green roof (kg/m^2)							
	Tree	Shrub	Herb	2016				2017			
				Tree	Shrub	Herb	Total	Tree	Shrub	Herb	Total
APR	62	23	15	1.27	0.08	0.09	1.44	1.29	0.09	0.09	1.47
ASH	74	10	16	3.54	0.01	0.14	3.70	3.59	0.02	0.14	3.74
MHT	72	14	14	14.46	0.53	0.07	15.06	14.80	0.52	0.08	15.40
MTK	58	29	12	1.27	0.31	0.01	1.59	1.33	0.32	0.01	1.66
SGK	0	0	100	0.00	0.00	0.11	0.11	0.00	0.00	0.00	0.00
SGT	26	65	9	0.17	0.06	0.01	0.24	0.13	0.07	0.01	0.21
SXV	89	11	0	0.23	0.02	0.00	0.25	0.27	0.02	0.00	0.29
Average	54	22	24	2.99	0.14	0.06	3.20	3.06	0.15	0.05	3.25
SD	31	21	34	5.20	0.20	0.06	5.38	5.32	0.20	0.06	5.51

The total carbon storage on most of the green roofs, namely APR, ASH, MHT, MTK, and SXV, increased from 2016 to 2017 (Figure 4.6), with the largest increase of 137.08 kg/year of carbon storage on ASH. On SGK and SGT, however, the total carbon storage decreased, with as much as 121.46 kg on SGK due to the cancellation of the educational farming plot on the rooftop.

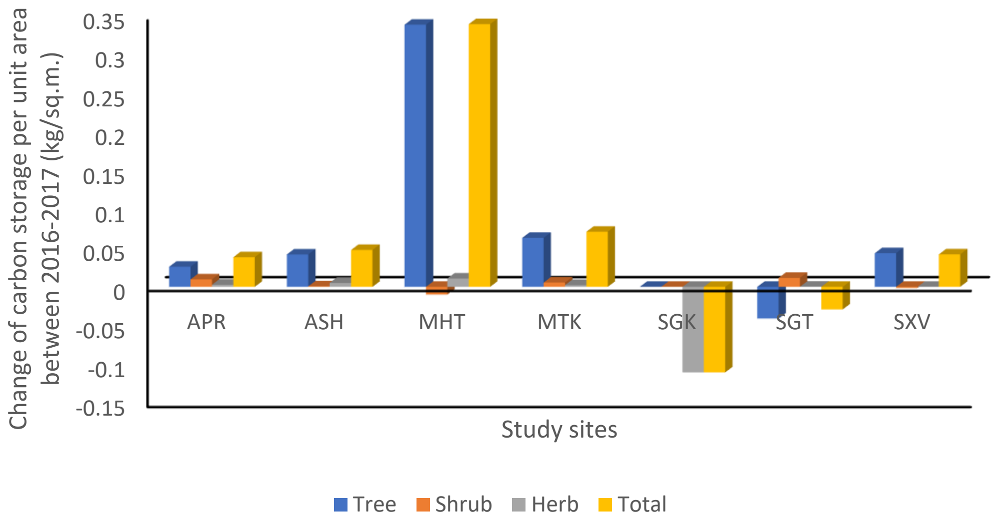


Figure 4.6 Amount of aboveground carbon storage on green roofs that changed between 2016-2017

4.3.2. Provisioning services: Cost and monetary benefit from the vegetation on green roofs in provisioning service aspects

The evaluation of green roof provisioning services was conducted in January 2017. The plant species found on the green roofs in this study could possibly be used as edible, medicinal, ornamental plants, and other uses. All of 77 plant species grown on the green roofs were initially designated as ornamental plants. Of the total plant species, 61% of the species had the potential to be used as medicinal plants and 10% were edible plants. The possible utilizations of each plant species are presented in Table 4.4. Seventeen percent of the total species have more than one potential utilization.

The edible plants observed on the green were fruit trees and home-grown vegetables, such as *Mangifera indica* and *Melampodium divaricatum*. Plant parts of the potentially medicinal plants can be used as ingredients of herbal medicines. For example, *Murraya paniculata* was used as traditional Chinese medicine for treating acne, and roots of *Millingtonia hortensis* had antipyretic properties (Medicinal Plants Information Center, 2017). Furthermore, 13 plant species could provide other types of provisioning ecosystem services. For instance, *Acacia auriculiformis* could provide timber for making furniture while *Chrysopogon zizanioides* was usually used for roofing. Moreover, leaves from *Ravenala madagascariensis* could be used to create handcrafts, and *Artabotrys siamensis* was one of the ingredients in traditional Thai perfume, due to their scented flowers. Some plant species on the green roofs could potentially be utilized for various purposes. For example, *Clitoria terratea* has flowers which can be eaten and used as medicinal ingredients, and various plant parts of *Coconus nucifera* can be used as food, timber, and herbal medicine.

Table 4.4 Possible utilization of vegetation found on the green roofs

Plant species	Thai name	Type of possible utilization			
		Edible	Medicinal	Ornamental	Other uses
Acacia auriculaeformis	กระถินณรงค์			✓	✓ Timber
Adonidia merrillii	หมากนวล		✓	✓	
Aechmea fasciata	สับปะรดสี			✓	
Aerva sanguinolenta	แดงชาลี			✓	
Alocasia macrorrhizos	กระดาด		✓	✓	
Artabotrys siamensis	การเวก		✓	✓	✓ Traditional Thai perfume
Asplenium nidus	เฟิร์นข้าหลวง		✓	✓	
Asystasia gangetica	บุษบาริมทาง ใบด่าง		✓	✓	
Axonopus compressus	หญ้ามาเลเซีย			✓	
Bambusa sp.	ไผ่		✓	✓	✓ Timber
Bougainvillea spectabilis	เฟื่องฟ้า		✓	✓	
Callisia fragrans	กวนอิมพันมือ			✓	
Caryota urens	เต่าร้าง		✓	✓	
Cerbera odollam	ตีนเป็ดน้ำ		✓	✓	
Cheilocostus speciosus	เอื้องอินโด		✓	✓	
Chlorophytum laxum	เศรษฐีเรือนนอก			✓	
Chrysopogon zizanioides	หญ้าแฝก		✓	✓	✓ Roofing
Clitoria ternatea	อัญชัน	✓	✓	✓	

Table 4.4 (continued)

Plant species	Thai name	Type of possible utilization			
		Edible	Medicinal	Ornamental	Other uses
Cocos nucifera	มะพร้าว	✓	✓	✓	✓ Timber
Codiaeum variegatum	โกสน		✓	✓	
Copernicia prunifera	ปาล์มแว็กซ์			✓	
Cordyline fruticosa	หมากผู้หมากเมีย หางหงส์		✓	✓	
Cynodon dactylon	หญ้าเบอร์มิวดา			✓	
Dieffenbachia seguine	ช้างเผือก			✓	
Dracaena loureirin	จันทน์ผา		✓	✓	
Dracaena surculosa	ไผ่ฟิลิปปินส์			✓	
Duranta erecta	เทียนทอง		✓	✓	
Dypsis lutescens	หมากเหลือง		✓	✓	
Ehretia microphylla	ชาฮกเกี้ยน		✓	✓	
Epipremnum aureum	พลูด่าง			✓	
Euphorbia pulcherrima	คริสมาสต์			✓	
Ficus annulate	ไทรอินโด			✓	
Ficus benjamina	ไทรย้อยใบแหลม		✓	✓	
Ficus microcarpa	ไทรทอง			✓	
Ficus pumila	ตีนตุ๊กแก		✓	✓	
Ficus sp.	ไทรเกาหลี		✓	✓	

Table 4.4 (continued)

Plant species	Thai name	Type of possible utilization				
		Edible	Medicinal	Ornamental	Other uses	
Gardenia jasminoides.	พุดสุภโชค			✓		
Graptophyllum pictum	ใบทอง		✓	✓		
Heliconia spp.	ธรรมรักษา ก้ามกุ้ง			✓		
Hibiscus spp.	ชบา		✓	✓		
Homalomena rubescens	ว่านเสน่ห์จันทร์แดง		✓	✓		
Hymenocallis littoralis	พลับพลึงตีนเป็ด		✓	✓		
Ixora chinensis	เข็มญี่ปุ่น			✓		
Ixora finlaysoniana	เข็มพวงขาว		✓	✓		
Ixora longifolia	เข็มเศรษฐีมาเลเซีย			✓		
Ixora macrothyrsa	เข็มเศรษฐี		✓	✓		
Mangifera indica	มะม่วง	✓	✓	✓	✓	Timber
Melampodium divaricatum	กะเทรา	✓	✓	✓		
Millingtonia hortensis	ปีบ		✓	✓	✓	Timber
Mimusops elengi	พิกุล		✓	✓	✓	Timber
Moringa oleifera	มะรุม	✓	✓	✓		
Murraya paniculata	แก้ว		✓	✓	✓	Traditional Thai perfume
Nephrolepis cordifolia	เฟิร์นใบมะขาม			✓		
Ocimum × *africanum*	แมงลัก	✓	✓	✓		

Table 4.4 (continued)

Plant species	Thai name	Type of possible utilization			
		Edible	Medicinal	Ornamental	Other uses
Ocimum basilicum	โหระพา	✓	✓	✓	
Pandanus amaryllifolius	เตยหอม	✓	✓	✓	
Pandanus tectorius	การะเกด		✓	✓	
Philodendron xanadu	ซานาดู			✓	
Phymatosorus scolopendria	เฟิร์นหลังลวน			✓	
Pisonia grandis	แสงจันทร์		✓	✓	
Plumeria rubra	ลั่นทม		✓	✓	✓ Traditional Thai perfume
Polyalthia longifolia	อโศกอินเดีย			✓	✓ Timber
Pritchardia pacifica	ปาล์มพัด			✓	
Pseuderanthemum carruthersii	ใบนาก		✓	✓	
Pseuderanthemum crenulatum	เข็มม่วง		✓	✓	
Ptychosperma macarthurii	หมากเขียว			✓	
Ravenala madagascariensis	กล้วยพัด			✓	✓ Handicrafts
Rhapis excelsa	จั๋ง			✓	
Ruellia squarrosa	ต้อยติ่งฝรั่ง		✓	✓	
Sansevieria spp.	ลิ้นมังกร		✓	✓	
Spathiphyllum spp.	เดหลี			✓	
Sphagneticola trilobata	กระดุมทอง		✓	✓	

Table 4.4 (continued)

Plant species	Thai name	Type of possible utilization			
		Edible	Medicinal	Ornamental	Other uses
Tabebuia aurea	เหลืองปรีดียาธร			✓	
Tabernaemontana pandacaqui	พุดร้อยมาลัย		✓	✓	
Thrinax parviflora	ปาล์มสะดือเขียว			✓	
Wodyetia bifurcata	ปาล์มหางกระรอก			✓	
Wrightia religiosa	โมกบ้าน		✓	✓	✓ Traditional Thai perfume
Total number of plant species		8	47	77	13

The edible plant species were not found on three green roofs, namely MHT, MTK, and SXV while medicinal, and ornamental plants, as well as plants with other uses in provisioning services were observed on all green roofs (Figure 4.7). SGK and APR provided the greatest number of four edible plant species and 18 medicinal plant species, respectively. The highest number of 33 ornamental plant species and seven plant species of the other use category were found on ASH.

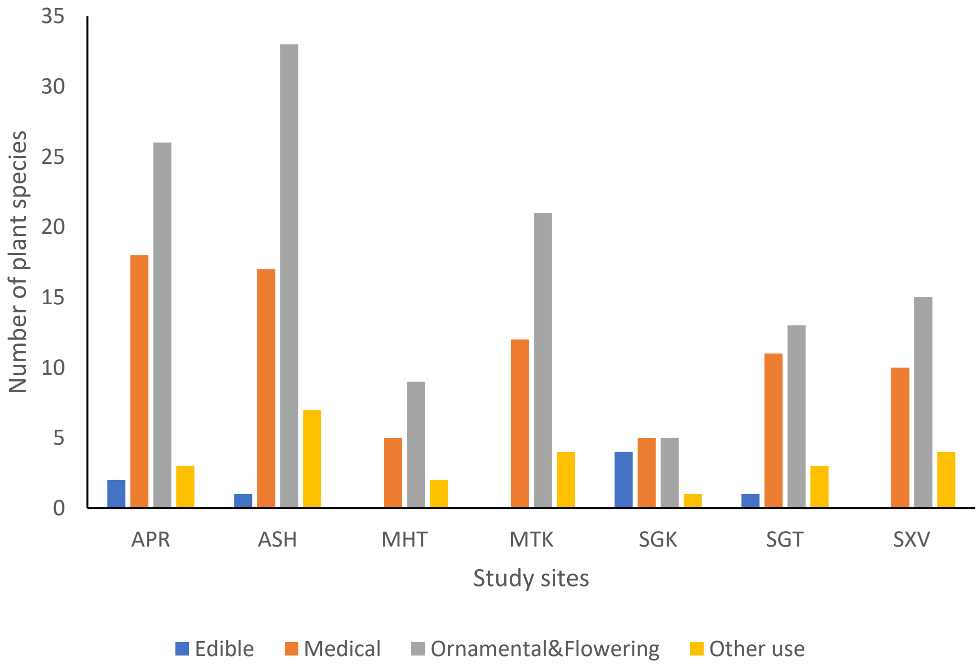


Figure 4.7 Number of plant species on each green roof separated into utilization types

Cover area of plant species in each use category found on the green roofs is presented in Appendix J. The variety of edible plant species on the green roofs was rather low. The dominant edible plant species on each green roof are presented in Table 4.5. Three species were trees that could provide edible products, namely *Moringa oleifera*, *Mangifera indica*, and *Cocos nucifera*. Only one vegetable species, *Melampodium divaricatum*, was found exclusively on SGK as the dominant edible species. The results in Table 4.6 revealed that apart from general medicinal herbs, other ornamental plants, such as *Artabotrys siamensis*, *Murraya paniculata*, and *Ficus benjamina*, could also provide medicinal benefits, according to the medicinal plant database in Thailand. Overall, the dominant ornamental plant species, including banyans and palm trees, found on the green roofs possessed the aesthetic characteristics appropriate for landscape design, namely ornamental flowers, foliage, and form (Table 4.7). Some green roofs did not have the variety of plant species for other uses (Table 4.8). On SGK, only *Chrysopogon zizanioides* was observed.

Table 4.5 Species composition of the edible plants on the green roofs in this stydy

Edible plant species	Thai name	%Species composition						
		APR	ASH	MHT	MTK	SGK	SGT	SXV
Clitoria ternatea	อัญชัน	10.3	-	-	-	-	-	-
Cocos nucifera	มะพร้าว	-	100.0	-	-	-	-	-
Mangifera indica	มะม่วง	-	-	-	-	-	100.0	-
Moringa oleifera	มะรุม	89.7	-	-	-	-	-	-
Ocimum × africanum	แมงลัก	-	-	-	-	40.1	-	-
Ocimum basilicum	โหระพา	-	-	-	-	11.1	-	-
Ocimum tenuiflorum	กะเพรา	-	-	-	-	45.7	-	-
Pandanus amaryllifolius	เตยหอม	-	-	-	-	3.1	-	-

Table 4.6 Species composition of the medicinal plant species on the green roofs in this study

Medicinal plant species	Thai name	%Species composition						
		APR	ASH	MHT	MTK	SGK	SGT	SXV
Adonidia merrillii	หมากนวล	3.8	-	-	-	-	-	-
Alocasia macrorrhizos	กระดาด	0.5	-	-	-	-	-	-
Artabotrys siamensis	การเวก	-	10.8	-	-	-	-	88.9
Asplenium nidus	เฟิร์น	-	0.4	-	-	-	-	-
Asystasia gangetica	ข้าหลวง บุษบาริม ทาง ใบด่าง	-	0.3	-	-	-	-	-
Bambusa sp.	ไผ่	-	0.1	-	7.5	-	-	-
Bougainvillea spectabilis	เฟื่องฟ้า	2.9	-	-	21.9	-	7.0	0.9
Caryota urens	เต่าร้าง	-	0.4	-	-	-	-	-
Cerbera odollam	ตีนเป็ดน้ำ	17.9	-	-	-	-	-	-
Cheilocostus speciosus	เอื้องอินโด	-	0.4	-	-	-	-	-
Chrysopogon zizanioides	หญ้าแฝก	-	-	-	-	6.3	-	-
Clitoria ternatea	อัญชัน	0.5	-	-	-	-	-	-
Cocos nucifera	มะพร้าว	-	17.2	-	-	-	-	-
Codiaeum variegatum	โกสน	0.3	-	-	-	-	-	-
Cordyline fruticosa	หมากผู้ หมากเมีย หางหงส์	-	0.4	-	-	-	-	-
Dracaena loureirin	จันทน์ผา	-	0.5	-	0.7	-	-	-

Medicinal plant species	Thai name	%Species composition						
		APR	ASH	MHT	MTK	SGK	SGT	SXV
Duranta erecta	เทียนทอง	-	-	-	0.1	-	-	-
Dypsis lutescens	หมากเหลือง	-	3.8	-	-	-	2.2	-
Ehretia microphylla	ชาฮกเกี้ยน	-	-	-	5.9	-	-	-
Ficus benjamina	ไทรย้อยใบแหลม	7.0	63.3	-	-	-	14.6	-
Ficus pumila	ตีนตุ๊กแก	-	-	-	2.3	-	-	-
Ficus sp.	ไทรเกาหลี	-	-	-	7.8	-	34.2	0.5
Graptophyllum pictum	ใบทอง	-	-	10.3	-	-	-	-
Hibiscus spp.	ชบา	1.6	-	-	-	-	-	-
Homalomena rubescens	ว่านเสน่ห์จันทร์แดง	1.2	-	-	-	-	-	-
Hymenocallis littoralis	พลับพลึงตีนเป็ด	3.0	0.7	18.7	-	-	6.3	-
Ixora finlaysoniana	เข็มพวงขาว	-	0.9	-	-	-	-	-
Ixora macrothyrsa	เข็มเศรษฐี	7.2	-	-	11.9	-	6.3	-
Mangifera indica	มะม่วง	-	-	-	-	-	12.5	-
Melampodium divaricatum	กะเพรา	-	-	-	-	42.8	-	-
Millingtonia hortensis	ปีบ	-	-	19.6	-	-	-	-
Mimusops elengi	พิกุล	-	-	-	4.9	-	-	-
Moringa oleifera	มะรุม	4.6	-	-	-	-	-	-
Murraya paniculata	แก้ว	25.6	-	-	-	-	0.2	-
Ocimum × africanum	แมงลัก	-	-	-	-	37.6	-	-
Ocimum basilicum	โหระพา	-	-	-	-	10.4	-	-
Pandanus amaryllifolius	เตยหอม	-	-	-	-	2.9	-	-
Pandanus tectorius	การะเกด	-	0.3	-	-	-	-	-
Pisonia grandis	แสงจันทร์	-	-	-	-	-	4.9	1.8
Plumeria rubra	ลั่นทม	11.7	-	48.6	28.6	-	8.7	-
Pseuderanthemum carruthersii	ใบนาก	-	-	2.8	-	-	-	-
Pseuderanthemum crenulatum	เข็มม่วง	3.1	-	-	-	-	-	-
Ruellia squarrosa	ต้อยติ่งฝรั่ง	1.6	0.1	-	7.3	-	-	-
Sansevieria spp.	ลิ้นมังกร	-	0.1	-	-	-	-	-
Sphagneticola trilobata	กระดุมทอง	-	-	-	-	-	3.1	-
Tabernaemontana pandacaqui	พุดร้อยมาลัย	3.9	-	-	-	-	-	-
Wrightia religiosa	โมกบ้าน	3.6	0.3	-	1.1	-	-	7.9

Table 4.7 Species composition of the ornamental plant species on the green roofs in this study

Ornamental plant species	Thai name	%Species composition						
		APR	ASH	MHT	MTK	SGK	SGT	SXV
Acacia auriculaeformis	กระถินณรงค์	-	0.12	-	-	-	5.33	-
Adonidia merrillii	หมากนวล	3.21	-	-	-	-	-	-
Aechmea fasciata	สับปะรดสี	-	0.04	-	-	-	-	-
Aerva sanguinolenta	แดงชาลี	-	0.10	-	-	-	-	-
Alocasia macrorrhizos	กระดาด	0.43	-	-	-	-	-	-
Artabotrys siamensis	การเวก	-	8.46	-	-	-	-	85.91
Asplenium nidus	เฟิร์นข้าหลวง	-	0.32	-	-	-	-	-
Asystasia gangetica	บุษบาริมทาง ใบด่าง	-	0.24	-	-	-	-	-
Axonopus compressus	หญ้ามาเลเซีย	-	8.51	-	-	-	-	-
Bambusa sp.	ไผ่	-	0.09	-	3.24	-	-	-
Bougainvillea spectabilis	เฟื่องฟ้า	2.44	-	-	9.49	-	6.52	0.89
Callisia fragrans	กวนอิมพันมือ	1.33	-	-	-	-	-	-
Caryota urens	เต่าร้าง	-	0.33	-	-	-	-	-
Cerbera odollam	ตีนเป็ดน้ำ	15.00	-	-	-	-	-	-
Cheilocostus speciosus	เอื้องอินโด	-	0.30	-	-	-	-	-
Chlorophytum laxum	เศรษฐีเรือนนอก	-	0.05	-	-	-	-	-
Chrysopogon zizanioides	หญ้าแฝก	-	-	-	-	6.26	-	-
Clitoria ternatea	อัญชัน	0.44	-	-	-	-	-	-
Cocos nucifera	มะพร้าว	-	13.4 3	-	-	-	-	-
Codiaeum variegatum	โกสน	0.25	-	-	-	-	-	-
Copernicia prunifera	ปาล์มแว็กซ์	-	-	-	2.43	-	-	-
Cordyline fruticosa	หมากผู้หมาก เมีย หางหงส์	-	0.35	-	-	-	-	-
Cynodon dactylon	หญ้าเบอร์มิวดา	6.94	-	-	-	-	-	-
Dieffenbachia seguine	ช้างเผือก	0.14	-	-	-	-	-	-
Dracaena loureirin	จันทน์ผา	-	0.39	-	0.29	-	-	-
Dracaena surculosa	ไผ่ฟิลิปปินส์	-	0.10	-	-	-	-	-
Duranta erecta	เทียนทอง	-	-	-	0.02	-	-	-
Dypsis lutescens	หมากเหลือง	-	3.03	-	-	-	2.01	-
Ehretia microphylla	ชาฮกเกี้ยน	-	-	-	2.55	-	-	-
Epipremnum aureum	พลูด่าง	-	4.36	-	5.48	-	-	-
Euphorbia pulcherrima	คริสมาสต์	0.14	-	-	-	-	-	-
Ficus annulate	ไทรอินโด	-	-	-	4.66	-	-	-
Ficus benjamina	ไทรย้อยใบ แหลม	5.85	49.3 6	-	-	-	13.59	-
Ficus microcarpa	ไทรทอง	-	-	-	2.23	-	-	-
Ficus pumila	ตีนตุ๊กแก	-	-	-	1.01	-	-	-
Ficus sp.	ไทรเกาหลี	-	-	-	3.39	-	31.70	0.45

Ornamental plant species	Thai name	%Species composition						
		APR	ASH	MHT	MTK	SGK	SGT	SXV
Gardenia jasminoides.	พุดศุภโชค	3.67	-	-	0.29	-	-	-
Graptophyllum pictum	ใบทอง	-	-	5.08	-	-	-	-
Heliconia spp.	ธรรมรักษา ก้ามกุ้ง	-	0.91	-	-	-	-	-
Hibiscus spp.	ชบา	1.32	-	-	-	-	-	-
Homalomena rubescens	ว่านเสน่ห์จันทร์แดง	1.01	-	-	-	-	-	-
Hymenocallis littoralis	พลับพลึงตีนเป็ด	2.58	0.55	9.15	-	-	5.80	-
Ixora chinensis	เข็มญี่ปุ่น	2.65	-	9.27	5.56	-	-	-
Ixora finlaysoniana	เข็มพวงขาว	-	0.74	-	-	-	-	-
Ixora longifolia	เข็มเศรษฐีมาเลเซีย	0.69	-	-	-	-	2.01	-
Ixora macrothyrsa	เข็มเศรษฐี	6.06	-	-	5.17	-	5.80	-
Mangifera indica	มะม่วง	-	-	-	-	-	11.59	-
Melampodium divaricatum	กะเพรา	-	-	-	-	42.82	-	-
Millingtonia hortensis	ปีบ	-	-	9.63	-	-	-	-
Mimusops elengi	พิกุล	-	-	-	2.14	-	-	-
Moringa oleifera	มะรุม	3.83	-	-	-	-	-	-
Murraya paniculata	แก้ว	21.43	-	-	-	-	0.16	-
Nephrolepis cordifolia	เฟิร์นใบมะขาม	-	0.05	-	-	-	-	-
Ocimum × africanum	แมงลัก	-	-	-	-	37.58	-	-
Ocimum basilicum	โหระพา	-	-	-	-	10.41	-	-
Pandanus amaryllifolius	เตยหอม	-	-	-	-	2.92	-	-
Pandanus tectorius	การะเกด	-	0.20	-	-	-	-	-
Philodendron xanadu	ซานาดู	0.37	-	-	-	-	-	-
Phymatosorus scolopendria	เฟิร์นหลังสวน	-	0.25	6.75	2.24	-	-	-
Pisonia grandis	แสงจันทร์	-	-	-	-	-	4.53	1.79
Plumeria rubra	ลั่นทม	9.80	-	23.84	12.40	-	8.05	-
Polyalthia longifolia	อโศกอินเดีย	-	0.05	-	-	-	-	-
Pritchardia pacifica	ปาล์มพัด	-	5.53	-	-	-	-	-
Pseuderanthemum carruthersii	ใบนาก	-	-	1.35	-	-	-	-
Pseuderanthemum crenulatum	เข็มม่วง	2.63	-	-	-	-	-	-
Ptychosperma macarthurii	หมากเขียว	-	0.59	10.84	-	-	-	3.36
Ravenala madagascariensis	กล้วยพัด	-	0.67	-	-	-	-	-
Rhapis excelsa	จั๋ง	-	0.36	-	-	-	-	-
Ruellia squarrosa	ต้อยติ่งฝรั่ง	1.37	0.05	-	3.17	-	-	-
Sansevieria spp.	ลิ้นมังกร	-	0.06	-	-	-	-	-
Spathiphyllum spp.	เดหลี	-	-	-	0.43	-	-	-
Sphagneticola trilobata	กระดุมทอง	-	-	-	-	-	2.90	-
Tabebuia aurea	เหลืองปรีดียาธร	-	-	24.09	-	-	-	-
Tabernaemontana pandacaqui	พุดร้อยมาลัย	3.35	-	-	-	-	-	-

Ornamental plant species	Thai name	%Species composition						
		APR	ASH	MHT	MTK	SGK	SGT	SXV
Thrinax parviflora	ปาล์มสะดือเขียว	-	0.39	-	-	-	-	-
Wodyetia bifurcata	ปาล์มหางกระรอก	-	-	-	33.31	-	-	-
Wrightia religiosa	โมกบ้าน	3.06	0.02	-	0.50	-	-	7.61

Table 4.8 Species composition of the plant species for other uses on the green roofs in this study

Plant species for other uses	Thai name	%Species composition						
		APR	ASH	MHT	MTK	SGK	SGT	SXV
Acacia auriculaeformis	กระถินณรงค์	-	0.5	-	-	-	21.4	-
Artabotrys siamensis	การเวก	-	37.1	-	-	-	-	91.9
Bambusa sp.	ไผ่	-	0.4	-	17.7	-	-	-
Chrysopogon zizanioides	หญ้าแฝก	-	-	-	-	100	-	-
Cocos nucifera	มะพร้าว	-	58.8	-	-	-	-	-
Mangifera indica	มะม่วง	-	-	-	-	-	46.4	-
Millingtonia hortensis	ปีบ	-	-	28.8	-	-	-	-
Mimusops elengi	พิกุล	-	-	-	11.7	-	-	-
Murraya paniculata	แก้ว	62.5	-	-	-	-	-	-
Plumeria rubra	ลั่นทม	28.6	-	71.2	67.9	-	32.2	-
Polyalthia longifolia	อโศกอินเดีย	-	0.2	-	-	-	-	-
Ravenala madagascariensis	กล้วยพัด	-	2.9	-	-	-	-	-
Wrightia religiosa	โมกบ้าน	8.9	0.1	-	2.7	-	-	8.1

Table 4.9 presents the installation cost of vegetation and income of provision services including expected selling prices for edible production and ornamental plants on green roofs. The results showed that the green roofs with average area of 1,070 m^2 used the average installation cost about 186,071 THB or about 196 THB/m^2. ASH had the highest total installation cost whereas SGT had the lowest total installation cost. The installation cost per unit area of MHT was the most expensive (408 THB/m^2). The lowest installation cost per unit area of SXV was the lowest (26 THB/m^2). The installation cost for the flowerpot-design green roofs (SGT and SXV) were considerably cheaper than that of the green roofs of the garden bed design. The average installation cost of garden bed design green roofs was 206 THB/m^2 while the flowerpot design green roofs had average of 36 THB/m^2 of installation cost and it was about 6 times as high as garden bed design.

The average total expected monetary benefits from edible and ornamental plants on the green roofs was 60,206 THB or 98 THB/m^2. The highest monetary benefits per green roof unit area belonged to MHT (350 THB/m^2) while ASH and SXV had the lowest monetary benefits of 18 THB/m^2. MTK had the highest monetary benefits of 158 THB/m^2 whereas SGT had the lowest monetary benefits of 50 THB/m^2. SGK had the highest edible plant monetary benefits of 7 THB/m^2. MHT, MTK, and SXV had no income from expected edible production due to the lack of edible plants.

Table 4.9 Installation cost and expected monetary benefits from vegetation in provisioning service aspects of the green roofs

Study sites	Area	Cost (THB)			Cost/m^2	Monetary benefits (THB)			Monetary Benefits/m^2
	(m^2)	Materials	Labor	Total		Edibles	Ornamentals	Total	
APR	891	143874	54229	198103	222	1809	63841	65650	74
ASH	2872	366909	117146	484055	169	5173	45515	50688	18
MHT	287	97336	19815	117151	408	0	100393	100393	350
MTK	942	253324	62532	315856	335	0	148602	148602	158
SGK	1098	74042	63055	137097	125	7693	15992	23685	22
SGT	238	14213	5885	20098	84	78	11902	11980	50
SXV	1159	20250	9890	30140	26	0	20445	20445	18

4.3.3. Cultural services: Potential in providing recreational and educational space

The assessment of cultural services on green roofs was conducted in February 2017. The accessibility and popular green roof visiting time of each green roof are presented in Tables 4.10 and 4.11, respectively. Five green roofs (APR, ASH, MHT, MTK, and SXV) were opened during business hours (7:00AM – 7:00PM). The people who live or work in the building were allowed to use the green roofs during the opening time. Then, these five green roofs achieved the accessibility standard. In addition, the opening-closing time for accessing and using green roofs could assist in safety for green roof visitors. The visitors of these five green roofs were also limited to building residents. Furthermore, ASH and MTK had security guards to take care of safety on green roof. On the other hand, SGT and SGK did not achieve this standard. SGT was a green roof with a restricted access. While SGK was formerly the rooftop farming with the educational purpose, then firstly the people were allowed to participate many agricultural activities on the green roof. However, unfortunately, it was abandoned and closed in February 2017. After that, the people could not access the green roof and all educational activities ceased. Quantity standards in this study were presented as the number of visitors. The number of visitors who visited and used the five open green roofs ranged from 10 to 30 people per day. There were various types of green roof visitors including students, officers, and residents of the buildings. The green roofs on university buildings were used on weekdays. MHT was highly used at lunch time, in the afternoon and evening while SXV and APR were highly used in the morning and evening. The green roofs on hotels or residences were used on weekdays and weekend. ASH was highly used in daytime (10:00 a.m.-4:00 p.m.) while MTK was highly used in weekend evening.

Table 4.10 Accessibility of the green roofs

Study sites	Accessibility	No. of visitors per day	Type of visitors
APR	Yes	10	Students, professors, and officers of the university
ASH	Yes	30	Residents
MHT	Yes	30	Students, professors, and officers of the university
MTK	Yes	20	Residents
SGK	No	0	-
SGT	No	0	-
SXV	Yes	10	Students, professors, and officers of the university

Table 4.11 Popular visiting time of the green roofs

Study sites	Green roof visiting time				
	Morning (7:00-11:00 AM)	Lunch (11:00AM-1:00PM)	Afternoon (1:00-4:00PM)	Evening (4:00-7:00PM)	Notes
APR	✓	-	-	✓	-
ASH	-	✓	✓	-	Also 10:00-11:00 AM-
MHT	-	✓	✓	✓	-
MTK	-	-	-	✓	-
SGK	-	-	-	-	-
SGT	-	-	-	-	-
SXV	✓	-	-	-	-

The service standards consisted of the existence of facilities, services, and activities. Most of the green roofs in this study were constructed for recreation purpose; therefore, many facilities were installed on the green roofs. Table 4.12 and Figure 4.8 show the core facilities observed on each green roof. ASH and MTK contained the highest number of core facility types including tables, chairs, sunshade, footpath, light bulbs. ASH also had a playground on the green roof. On the contrary, MHT and SGK provided only footpaths.

Table 4.12 Facilities on the green roofs

Study sites	Core facilities					
	Table/ Chair	**Sunshade/ Umbrella**	**Footpath**	**Playground**	**Swimming pool**	**Electric light**
APR	✓		✓		✓	
ASH	✓	✓	✓	✓	✓	✓
MHT			✓			
MTK	✓	✓	✓		✓	✓
SGK			✓			
SGT			✓			✓
SXV			✓			

(a)

(b)

(c)

Figure 4.8 Facilities provided on the green roofs: (a) Electric light, (b) Sunshade/Umbrella, and (c) Swimming pool

In addition to the core facilities, the services were observed on the green roofs, including maintenance and management, which differed among the buildings in this study. Cleanliness of a green roof was the important aspect that was considered for the aesthetic reason. Therefore, fallen leaves on most of the green roofs were removed by gardeners. However, on SGT and SGK that fallen leaves were not removed and naturally decomposed. The fallen leaves on ASH were used for composting. All green roofs had similar maintenance activities for the vegetation but the frequency of each activity was different among the study sites. The vegetation maintenance activities found on green roofs were watering, fertilization, and trimming.

The activities or utilizations for cultural services found on the green roofs in this study are summarized in Table 4.13. Three main activities observed on the green roofs included recreation, exercise and learning activity. APR, ASH, MHT, MTK, and SXV were used as recreational spaces. As APR, ASH, and MTK were also used as exercise areas, each green roof also contained a swimming pool. APR was specifically located on the same floor as the fitness center of the Faculty of Medicine, Chulalongkorn University. Therefore, apart from normal exercise and swimming, aquatic therapy was one of the activities that was observed on this green roof. SGK and ASH provided educational space for the visitors. SGK was formerly constructed as the learning center for urban agriculture as well as a community garden. Therefore, many facilities for learning support were available, such as plant labels and knowledge boards. In the past, several urban farming activities were conducted on this green roof. However, SGK was closed during the study period (February 2017) and people were no longer allowed to access and use; therefore, the potential of SGK for providing cultural services in terms of learning and recreation benefits was lower than the past. Although there was no facility for learning support on ASH, learning activities were conducted through sharing the knowledge about bird species found on ASH to the hotel staffs.

Table 4.13 Utilization found on the green roofs

Study sites	**Type of utilization**			
	Recreation	**Exercise**	**Educational space**	**Other utilizations**
APR	✓	✓		
ASH	✓	✓	✓	✓
MHT	✓			
MTK	✓	✓		
SGK	✓		✓	
SGT				✓
SXV	✓			

Table 4.14 shows the data of quantity and quality green space standards collected from the green roofs. Most of the green roofs were opened for people to access, except SGK and SGT. Therefore, the accessibility of only five green roofs, namely APR, ASH, MHT, MTK, and SXV, could be identified. The ratio of green roof area and possible number of people who can use the green roofs ranged from 0.6 to 2.3 m^2/person. More than 500 people who lived or worked in these five buildings could enter and use the green roofs. The investigation of quality standards showed that only six green roofs (APR, ASH, MHT, MTK, SGT, and SXV) had trees that could provide the shade. The amount of carbon that could be decreased by the green roofs could be indicated from the amount of carbon storage by the green roofs. Then, the potential in carbon storage on the green roofs ranged from 0.11 to 15.06 kg/m^2 (Table 4.3). The plant species found on the study sites were suitable for green roofs since the plants were either native species, such as *Ficus benjamina*, *Hibiscus* spp., and *Millingtonia hortensis*, which have been recommended by the Office of Natural Resources and Environmental Policy and Planning (2014), or non-native species (i.e. *Acacia auriculaeformis*, *Plumeria rubra*, and *Polyalthia longifolia*) which originate from the countries with similar habitats to Thailand and could adjust to the environment and climate in Thailand. The non-native plant species found in this study were also in the plant list for urban green spaces in Thailand suggested by the Forest Research and Development Office (2016), the Faculty of Natural Resources Prince of Songkla University (2018) and the Office of Natural Resources and Environmental Policy and Planning (2014).

Table 4.15 presents the results from the evaluation of green roof cultural services using the green space standards developed by the Natural Resources and Environmental Policy and Planning (Office of Natural Resources and Environmental Policy and Planning, 2014). Twelve criteria were assessed in this study. APR, ASH, MHT, MTK, and SXV could achieve eight criteria while SGK and SGT attained four and two criteria, respectively.

Table 4.14 Evaluation results of the quantity and quality green space standards of the green roofs

No.	Standards	APR	ASH	MHT	MTK	SGK	SGT	SXV
Quantity and accessibility standards								
1	Ratio of green area and population	1.8	5.7	0.6	1.9	0	0	2.3
2	Size of green area (m^2)	891.30	2871.97	287.42	942.30	1097.90	237.56	1159.20
3	Number of people that can use the green area	>500	>500	>500	>500	0	0	>500
4	Accessibility (Yes/No*)	Yes	Yes	Yes	Yes	No	No	Yes
Quality standards								
Sustainable green area								
5	Number of trees in sustainable green area	60	114	77	56	0	3	60
Decreasing temperature								

No.	Standards	APR	ASH	MHT	MTK	SGK	SGT	SXV
6	Trees that provide the shade for opened area	45	96	57	47	0	1	3
Decreasing air pollution								
7	Decreasing CO_2 (kg/m^2)	1.44	3.7	15.06	1.59	0.11	0.24	0.25
Soil and water conservation								
8	Water-permeable area (m^2)	27.90	28.93	65.55	22.28	46.94	8.74	1.88
Biodiversity								
9	Diversity of vegetation in green area (%)	>5	>5	>5	>5	>5	>5	>5
10	Vertical vegetation (%)	62.09	83.41	77.00	58.46	0.00	22.19	89.26
Vegetation selection								
11	Suitable vegetation for ecology (%)	100	100	100	100	100	100	100
12	Suitable vegetation for type of green area (%)	46	9	82	3	0	25	38

Note: * ‘Yes’ means the residents or officers of the buildings could access the green roof and ‘No’ means the people were not allowed to access the green roof.

Table 4.15 Evaluation of green roof cultural services using the green space standards

No.	Standards	APR	ASH	MHT	MTK	SGK	SGT	SXV
Quantity and accessibility standards								
1	Ratio of green area and population	1	1	0	1	0	0	1
2	Size of green area	1	1	1	1	1	1	1
3	Number of people that can use the green area	1	1	1	1	0	0	1
4	Accessibility	1	1	1	1	0	0	1
Quality standards								
Sustainable green area								
5	Number of trees in sustainable green area	1	1	1	1	0	1	1
Decreasing temperature								
6	Trees that provide the shade for opened area	1	1	1	1	0	1	1
Decreasing air pollution								
7	Decreasing CO_2	0	0	0	0	0	0	0
Soil and water conservation								
8	Water-permeable area	0	0	0	0	0	0	0
Biodiversity								
9	Diversity of vegetation in green area	0	0	0	0	0	0	0
10	Vertical vegetation	1	1	1	1	0	0	1
Vegetation selection								
11	Suitable vegetation for ecology	1	1	1	1	1	1	1
12	Suitable vegetation for type of green area	0	0	1	0	0	0	0
Total number of achieved criteria (points)		8	8	8	8	4	2	8

Notes: score of one (1) means the green roof passed the criterion for a standard, and zero (0) means the green roof did not achieve the criterion.

4.3.4. Supporting services: Diversity of meso- and macro-soil fauna

The assessment of supporting services was conducted in May 2016. The average plant cover and average weight of leaf litter found in the sampling plots on the green roofs in this study are presented in Table 4.16. The plant cover on the green roofs ranged from 10% to 90%. The lowest plant cover was found on SXV while MTK had the highest plant cover percentage. The average litter weight ranged from 0 to 127 g/m^2. The litter was not found on SGK sampling plots where there was no tree or shrub cover. The physical conditions of sampling plots are presented in Table 4.17. The results showed that the soils on all green roofs were weakly acidic with the average of pH ranging from 5.9 to 6.7. The soil on MTK had the highest acidity. The soils of the study green roofs were rather dry, except on MTK which had 53% soil humidity. The average soil temperature ranged from 24°C to 28°C.

Table 4.16 Biological factors measured on the green roofs in this study

Study sites	Average plant cover (%)	S.D.	Average litter weight (g)	S.D.
APR	30	±34.64	13	±3.51
ASH	37	±15.28	12	±7.51
MHT	40	±40.00	127	±105.67
MTK	90	±17.32	17	±20.82
SGK	67	±57.74	0	±0.00
SGT	83	±28.87	7	±3.61
SXV	10	±10.00	1	±4.04

Table 4.17 Biological factors measured on the green roofs in this study

Data collection date	Study sites	Soil pH	S.D.	Soil moisture (%)	S.D.	Soil temperature (°C)	S.D.
08/05/2016	APR	6.0	±0.50	17	±11.55	24	±0.00
10/05/2016	ASH	6.7	±0.14	10	±0.00	24	±1.00
12/05/2016	MHT	6.4	±0.38	10	±0.00	25	±0.00
15/05/2016	MTK	5.9	±0.38	53	±37.17	27	±0.00
17/05/2016	SGK	6.3	±0.66	7	±2.89	26	±0.58
19/05/2016	SGT	6.3	±0.52	7	±2.89	25	±0.00
22/05/2016	SXV	6.4	±0.14	15	±8.66	28	±1.00

The soil fauna found on the green roofs in this study belonged to ten orders, including Acari, Araneae, Diptera, Hymenoptera, Isopoda, Opisthopora, Polydesmida, Spirobolida, Stylommatophora, and Thysanoptera. The sample specimens of the soil fauna are shown in Figure 4.9. They can be divided into 3 groups, namely arthropods, earthworms, and snails. Furthermore, all orders are consumers and they can be also classified into two main groups of consumers: (1) herbivore, carnivore, and/or omnivore (i.e. Araneae, Diptera, Hymenoptera, Stylommatophora, and Thysanoptera) and (2) detritivores (i.e. Acari, Isopoda, Opisthopora, Polydesmida, and Spirobolida).

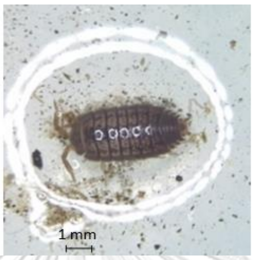
APR, MHT, and MTK had the greatest numbers of soil fauna orders while SGT provided the least number of orders (Figure 4.9). MHT had the greatest density of soil fauna while APR had the lowest density (Figure 4.10). Hymenoptera and Acari were found on all study sites. When found, a large number of individuals of Hymenoptera and Acari were observed while only a few specimens of the other eight orders were found.

Order Acari

Order Araneae

Order Diptera

Order Hymenoptera



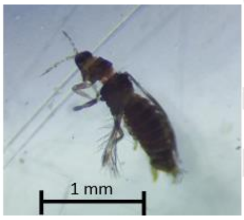
Order Isopoda

Order Opisthopora

Order Polydesmida

Order Spirobolida

Order Stylommatophora



Order Thysanoptera

Figure 4.9 Some examples of specimens of the soil fauna orders found on the green roofs in this study

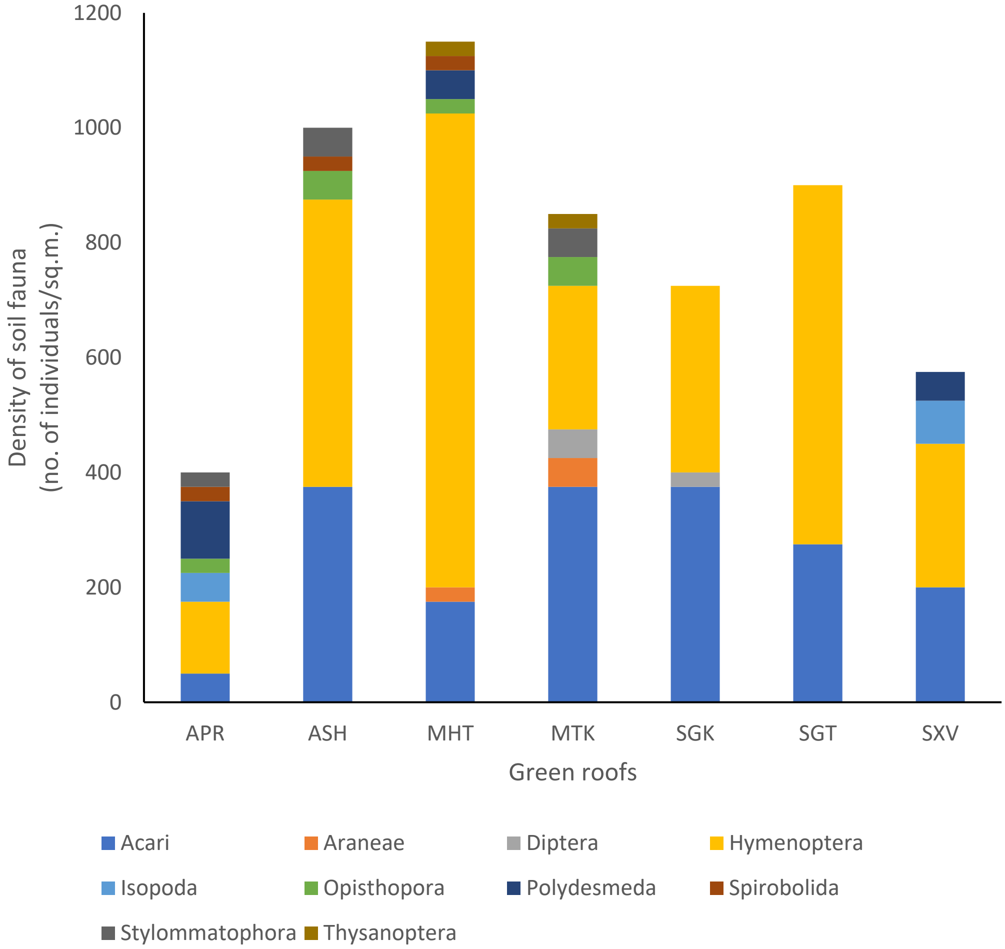


Figure 4.10 Density of soil fauna found on the green roofs in this study

The order richness of soil fauna, Shannon-Wiener Index and Simpon’s Index of the green roofs are presented in Table 4.18. The results showed that the soil fauna richness of the green roofs ranged from 0.28 to 2.16. The highest diversity of soil fauna was observed on APR (Shannon-Wiener Index = 1.75, Simpson's index of diversity = 0.80) while SGK (Shannon-Wiener Index = 0.48) and SGT (Shannon-Wiener Index = 0.62) had the low diversity of soil fauna. APR and ASH had the highest similarity of soil fauna orders (Sorensen’s similarity coefficient = 0.83) (Table 4.19).

Table 4.18 Soil fauna richness, Shannon-Wiener Index, and Simpson’s index of soil fauna diversity at the order level on the green roofs in this study

Study sites	Richness index	Shannon-Wiener’s Index	Simpson's index of diversity
APR	2.16	1.75	0.80
ASH	1.08	1.11	0.60
MHT	1.57	0.99	0.46
MTK	1.64	1.49	0.70
SGK	0.59	0.48	0.53
SGT	0.28	0.62	0.42
SXV	0.96	1.21	0.67

Table 4.19 Sorensen’s similarity coefficient of soil fauna on the green roofs in this study

Study sites	APR	ASH	MHT	MKT	SGK	SGT	SXV
APR	-	0.83	0.71	0.57	0.40	0.44	0.73
ASH	-	-	0.67	0.67	0.50	0.57	0.44
MHT	-	-	-	0.71	0.40	0.44	0.55
MKT	-	-	-	-	0.60	0.44	0.36
SGK	-	-	-	-	-	0.80	0.57
SGT	-	-	-	-	-	-	0.67
SXV	-	-	-	-	-	-	-

No relationship existed between the percentage of plant cover, soil pH, temperature, and weight of litter and soil fauna diversity (Table 4.20). Only soil moisture was correlated with Shannon-Wiener index and Simpson’s Index of soil fauna.

Table 4.20 Correlations between percentage of plant cover, soil pH, temperature, weight of litter and soil moisture and Shannon-Wiener index and Simpson's index of diversity

Correlations		Shannon-Wiener Index	Simpson's index of diversity
Percentage of plant cover	Correlation Coefficient	-0.357	-0.357
	Sig. (2-tailed)	0.432	0.432
	N	7	7
Soil pH	Correlation Coefficient	-0.346	-0.418
	Sig. (2-tailed)	0.448	0.350
	N	7	7
Soil temperature	Correlation Coefficient	-0.073	0.036
	Sig. (2-tailed)	0.877	0.938
	N	7	7
Weight of litter	Correlation Coefficient	0.500	0.214
	Sig. (2-tailed)	0.253	0.645
	N	7	7
Soil moisture	Correlation Coefficient	0.946*	0.873*
	Sig. (2-tailed)	0.001	0.010
	N	7	7

*Correlation is significant at the 0.05 level (2-tailed).

4.4. Plant selection and sustainability on intensive green roofs

Plumeria rubra, *Ficus benjamina*, and *Ptychosperma macarthurii* were the tree species most commonly used as they were found on all green roofs in this study. These three species were popular tree species used in landscape design in Thailand (Kampan, 2014). However, the tree species with the highest abundance were bamboos (*Bambusa multiplex*) and several palm species. Bamboos were used on two green roofs including ASH and MTK while palms were found on all green roofs except SGK. Palms have the fibrous root system which attaches well to the growing media and hardly causes damage to the building structure. In addition, several palm species can withstand winds and do not fall down (Faculty of Architecture and Environmental Design Maejo University, 2009).

Five major shrub species used on the green roofs are the species generally found on ground-level gardens and usually used for creating a living fence in landscape design (Office of Natural Resources and Environmental Policy and Planning, 2014). The use of *Ixora chinensis* and *Bougainvillea spectabilis* as living fences on MTK are shown in Figure 4.11. *Axonopus compressus*, a grass species, was the herbaceous species with the highest abundance found on seven green roofs. Using grass as ground cover instead of concrete on the green roof was suggested by the Office of Natural Resources and

Environmental Policy and Planning (2014) because of the benefits of decreasing building temperature and reducing the runoff outflow. *Epipremnum aureum* and *Hymenocallis littoralis* were also found commonly on the green roofs and they were used for creating the variety of vertical structure layers that would help green roofs mimic the natural ecosystems (Office of Natural Resources and Environmental Policy and Planning, 2014).

(a)

(b)

Figure 4.11 Use of shrubs as living fences: (a) *Ixora chinensis* and (b) *Bougainvillea spectabilis*

According to the Office of Natural Resources and Environmental Policy and Planning (2014), the objectives of green roof construction are to be recreational space and to create good environment. Therefore, the Office of Natural Resources and Environmental Policy and Planning suggested that small- to medium-sized plant species with high potential in carbon storage and pollution absorption should be grown on green roofs. From the total of 77 plant species found in this study, only two plant species with high potential in carbon storage (*Hibiscus* spp. and *Mangifera indica*) were found on the green roofs. Therefore, the high carbon storage potential was probably not the main criterion for plant species selection for the green roofs in this study. Furthermore, some plant species had the potential in air purifying such as *Clitoria ternatea*, *Murraya paniculata*, and *Wrightia religiosa* (Phutthai, Bhaktikul, and Pattanakiat, 2019). Chatakul (2010) reported that in general landscape design the popularity of trees depended on easy maintenance, beauty, and cost for growing. In addition, green roofs are restricted by various limitations, including structural constraints and harsh environmental conditions, trees with slow growth rate, shallow roots, and sparse crowns are preferred because these characteristics would allow plants to avoid damaging building structure, withstand stronger winds, and survive on green roofs. Therefore, plants with easy maintenance are recommended and plant pruning is also required (Faculty of Architecture and Environmental Design Maejo University, 2009; Office of Natural Resources and Environmental Policy and Planning, 2014). In this study, several plant species had the important characteristics for sustainability and survival on green roofs. For instance, *Ixora chinensis*, *Sansevieria* spp., and *Rhapis excelsa* are potentially tolerant to drought and require little maintenance (Lertpitiwatana, 2015).

4.5. Comparison between ecosystem service potential of different green roofs

4.5.1. Regulating services: Amount of aboveground carbon storage between May 2016 – 2017

The potential in carbon storage of the intensive green roofs in this study ranged from 0.11 kg/m^2 to 15.06 kg/m^2. Trees were the main contributing vegetation to the green roof carbon storage although the number of trees was smaller than that of other plant types on some green roofs. In this study, the average carbon storage of trees was 2.99 kg/m^2, which was substantially higher than that of shrubs (0.15 kg/m^2) and herbs (0.06 kg/m^2). Generally, trees could provide the higher carbon content than shrubs and herbaceous plants because of their wide stems and considerable heights (Office of Natural Resources and Environmental Policy and Planning, 2014; Ma et al., 2018). In this study, shrubs and herbs could store only 6- 35% and 1- 7% of the amount of tree carbon storage, respectively. Although planting trees could be a good choice for enhancing of carbon storage, the use of trees should be carefully considered due to limitations of green roofs, such as loading capacity, substrate depth, and availability of water resources as well as maintenance requirement. This is probably the reason that why trees were rarely found on the green roofs.

From 46 species of trees and shrubs found on the intensive green roofs in this study, the potential for carbon storage of 25 plant species were reported by the Office of Natural Resources and Environmental Policy and Planning (2014). The amount of carbon storage used as criteria for classifying carbon storage potential was proposed as high, medium, and low potential, which could store 32.3-39.9, 24.2-32.3, and 9.7-17.1 kg/tree/year of carbon, respectively. From the 25 species, only two tree species had the high carbon storage potential (*Hibiscus* spp. and *Mangifera indica*) and five species had medium carbon storage potential (*Acacia auriculiformis*, *Mimusops elengi*, *Murraya paniculata*, *Plumeria rubra*, and *Ptychosperma macarthurii*). Most of the plants that were used on the intensive green roofs still have low potential for carbon storage such as *Tabebuia argentea*, *Millingtonia hortensis*, *Wrightia religiosa*, *Pisonia grandis*, and *Dypsis lutescens*. Due to the limitation on green roofs, such as limited area for planting, loading capacity, and building structure, slow-growing plants were preferable to fast-growing plants in order to avoid overloading and destroying a rooftop (Lertpitiwatana, 2004). Moreover, harsh conditions on green roofs that vegetation would be facing also influenced the selection of plant species. Then, although some plants had a low potential for carbon storage, they were selected because of other suitable traits, such as sun tolerance in *Wrightia religiosa* and drought tolerance in *Dypsis lutescens* (Veesommai et al., 2008). Therefore, in addition to plant types and their potential in carbon storage, the sustainability and ability of plants to survive in harsh conditions, strong winds, high temperature, drought, as well as limited loading capacity of a building should be considered.

Overall, from 2016-2017 the increase in total aboveground carbon storage on the intensive green roofs in this study ranged from 0.04 to 0.34 kg/m^2/year. The average annual increase was 2.57% of total carbon storage in the first year. The carbon storage in trees and shrubs on MHT and SXV slightly decreased because of maintenance trimming. The whole amount of carbon storage on SGK disappeared by

2017 because the educational farming activities were cancelled and all vegetation on the green roof was abandoned and eventually died.

Belowground carbon storage of plants could also contribute significantly to the total carbon storage on green roofs. Chen (2015) investigated the distribution of carbon content of green roofs with C3, C4, and CAM plants and reported that the belowground carbon storage provided 6- 45% of the total carbon storage on the green roofs. Therefore, the potential for carbon storage on intensive green roofs could be higher when the belowground carbon storage is included in the estimation. Hence, further study of the belowground and soil carbon storage on intensive green roofs would describe the complete picture of the carbon storage potential on intensive green roofs.

The storage of aboveground carbon on intensive green roofs was also dependent on the number and proportions of trees of different sizes. In a green roof with a relatively high density of trees, especially large trees, would have a higher potential for carbon storage, as seen in ASH (Figures 4.12 and 4.13). *Ficus Benjamina* and *Cocos nucifera* were found on ASH and both of them had large DBH, with the largest DBH sizes more than 95 and 28 cm, respectively, and the average height of trees of 4.9 m. The important contribution of large trees on the total carbon storage was seen in MHT which had a higher number of trees of larger sizes than MTK, where a higher number of trees were observed. On MHT, several large *Millingtonia hortensis* trees were observed, with the largest tree of more than 34 cm DBH and 5 m height. Carbon sequestration rate on horizontal and vertical green space are dependent upon diameter and height of trees (Othman and Kasim, 2016). In natural forests, carbon sequestration was correlated with tree size class and height (Terakunpisut, Gajaseni, and Ruankawe, 2007). Therefore, in addition to the number of trees, trees with large DBH and height could be considered when the carbon storage potential is the objective for construction of intensive green roofs.

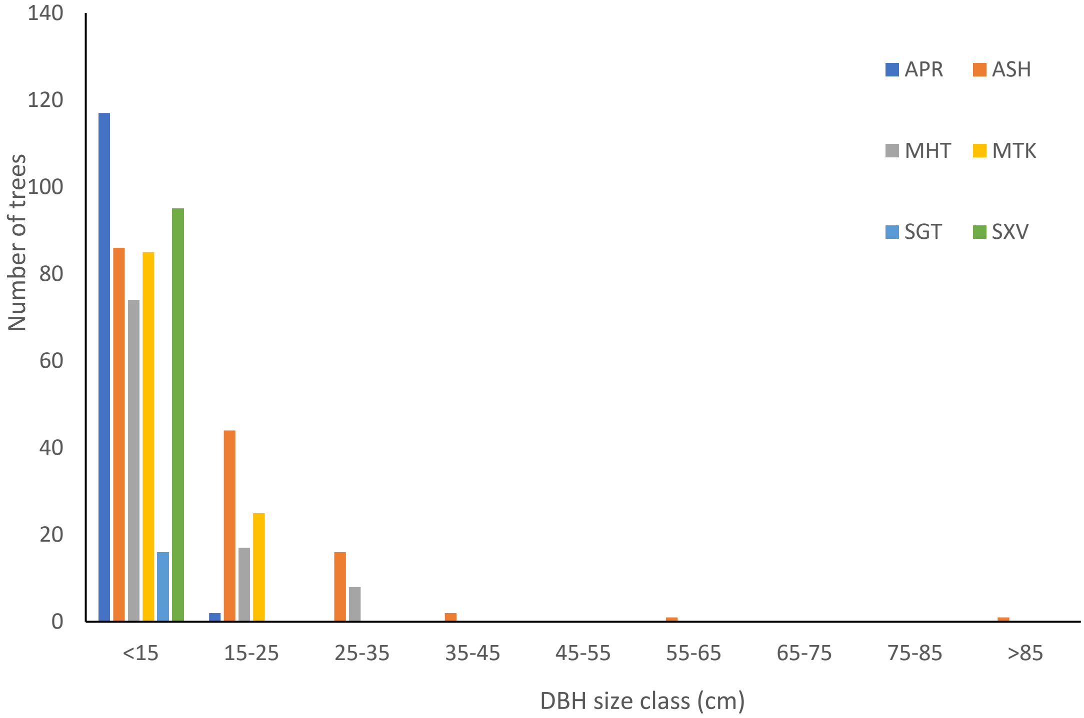


Figure 4.12 Tree size class distribution of the green roofs in this study in 2016

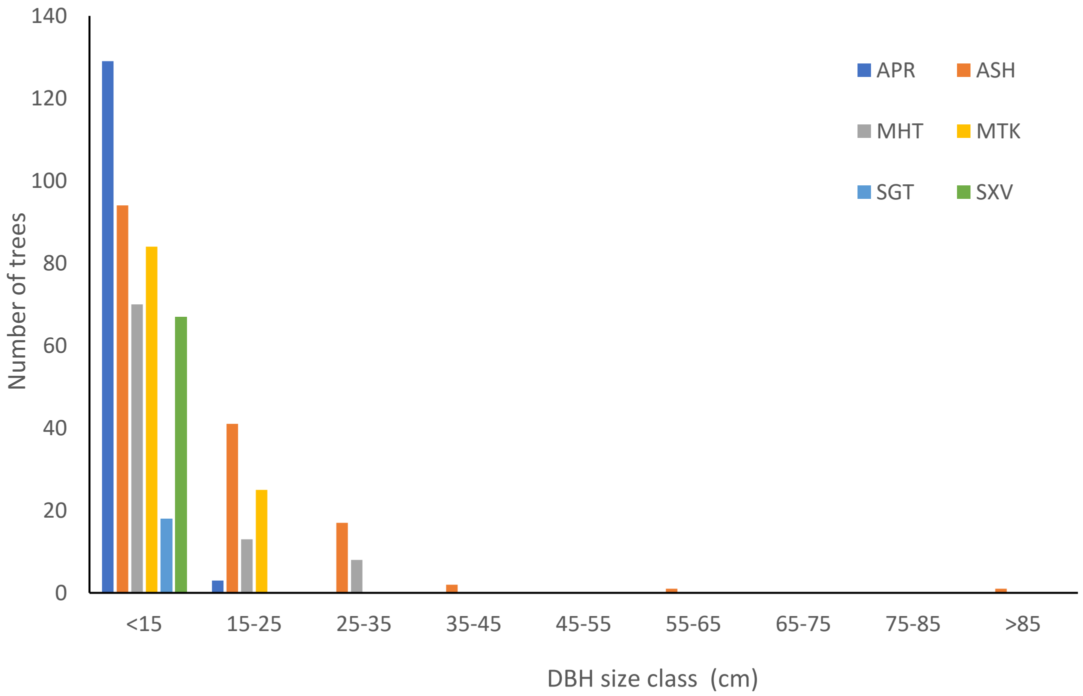


Figure 4.13 Tree size class distribution of the green roofs in this study in 2017

Palms could contribute substantially to the aboveground carbon storage on the green roofs in this study. Having similar green roof area and green area, the total carbon storage amounts on APR and MTK were similar even though the woody tree and herb carbon storage was lower in MTK. Figure 4.14 shows that half of total tree carbon storage on MTK was from palm trees. Palms were popularly used on intensive green roofs because they had tolerance to strong winds, high sunlight, and drought on green roofs. In addition to a landscape design aspect, palms generally have a fast rate of carbon accumulation and could therefore become a carbon sink (Dey, Islam, and Masum, 2014), potentially enhancing the carbon storage capability of green roofs.

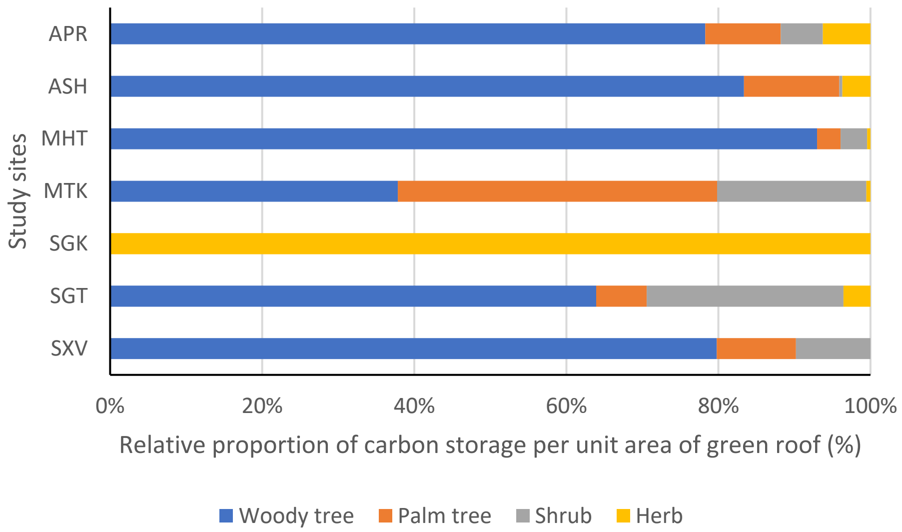


Figure 4.14 Relative proportion of carbon storage on the green roofs as measured in 2016

The green roofs with the lowest amount of total carbon were SGT, SGK, and SXV. The flowerpot design could explain the low amount of carbon storage on SGT and SXV. Flowerpot green roofs usually had shallow substrate in discrete locations on the roof surface, primarily limiting the number of trees and shrubs on the green roofs. Furthermore, small pots could limit root growth (Pennisi, 2015). SGK was formerly a rooftop farming site but the vegetables and herbs wilted and all of them eventually died during the study period due to lack of several maintenance activities, such as watering plants and fertilizer application. Therefore, the amount of carbon storage on SGK was very low in 2016 and completely disappeared in 2017.

The potential for carbon storage of intensive green roofs in this study were compared with ones of other urban ecosystems (Table 4.21). Most of the intensive green roofs in this study could store more carbon than average extensive green roofs. This is because intensive green roofs usually support more variety of plant types, including woody trees and shrubs, comparing with extensive green roofs (Oberndorfer et al., 2007). Therefore, carbon storage potential on intensive green roofs is normally higher than on extensive green roofs, which are mainly covered by shallow growing media layers and low plant biomass (Lundholm and Williams, 2015).

However, the carbon storage on SGK (0.11 kg/m^2) was similar to that of extensive green roofs (0.16 kg/m^2) (Getter et al., 2009). Constructed as a space for educating the public on farming, the vegetation found on SGK consisted only herbaceous vegetables and grasses. Furthermore, during the study period, SGK, originally classified as the intensive green roof type, was abandoned and all vegetation died.

Although the average amount of carbon storage on the green roofs in this study (3.20 kg/m^2) was considerably less than 15.62 kg/m^2 of urban forest, some intensive green roofs could provide carbon storage amount that were similar or more than other urban ecosystems. MHT stored 15.06 kg/m^2 of carbon that was quite high and close to one of 15.62 kg/m^2 of urban forest in Rotterdam (Derkzen, Teeffelen, and Verburg, 2015). Nevertheless, the characteristics of MHT, namely a high number of trees of large sizes, apparently distinguished it from the other green roofs. Thus, MHT could store the high amount of carbon despite of its limited green roof area resulting in the highest amount of carbon storage per unit area in this study. ASH could serve 3.70 kg/m^2 of carbon and it was similar to the carbon amount stored in the entire 73 km^2 of urban area in Leicester (Davies et al., 2011). While amount of carbon stored on APR and MTK were also more than one of 12.57 km^2 of domestic garden in Rotterdam (Derkzen et al., 2015). In addition to the carbon amounts, the results suggested that the characteristics of those urban ecosystems were also similar to the intensive green roofs. Urban forest and MHT had a relatively higher proportions of trees in clusters, enabling a higher potential of carbon storage. Domestic gardens included private gardens in residential zones and was composed of herbaceous, shrub, and tree that was similar to APR and MTK where a high variety of vegetation was found. Hence, the findings confirmed the availability of carbon storage on intensive green roofs could be as high as other urban ecosystems but the supply for carbon storage on each intensive green roof would differ depending on the composition of their vegetation.

Table 4.21 Comparison of carbon storage on the green roofs in this study and other urban ecosystems

Sites	Location	Carbon Storage (kgC/m^2)	Comment	References
APR	Bangkok, Thailand	1.44	Intensive green roof consisted of trees, shrubs, herbs, and grass	This study
ASH	Bangkok, Thailand	3.70	Intensive green roof consisted of trees, shrubs, herbs, and grass	This study
MHT	Bangkok, Thailand	15.06	Intensive green roof consisted of trees, shrubs, and herbs	This study
MTK	Bangkok, Thailand	1.59	Intensive green roof consisted of trees, shrubs, and herbs	This study
SGK	Bangkok, Thailand	0.11	Intensive green roof consisted of herbs and grass	This study
SGT	Bangkok, Thailand	0.24	Intensive green roof consisted of trees, shrubs, and herbs	This study
SXV	Bangkok, Thailand	0.25	Intensive green roof consisted of trees and shrubs	This study
Average of 7 green roofs	Bangkok, Thailand	3.20	Intensive green roofs	This study
Extensive green roofs	Michigan and Maryland, USA	0.16	Extensive green roofs primarily composed of *Sedum* species	Getter et al., 2009
Entire urban area	Leicester, UK	3.16	Urban area including road verges, parks, gardens, riparian zones, golf courses, industrial enclaves, schools, brownfield sites	Davies et al., 2011
Urban forest	Rotterdam, the Netherlands	15.62	Woodland and clustered trees	Derkzen et al., 2015
Street trees	Rotterdam, the Netherlands	10.64	Individual trees	Derkzen et al., 2015
Domestic garden	Rotterdam, the Netherlands	1.07	Domestic garden consisted of a mix of vegetation	Derkzen et al., 2015

4.5.2. Provisioning services: Cost and monetary benefit from the vegetation on green roofs in provisioning service aspects

The installation cost of green roofs was difficult to estimate due to lack of providing data about construction cost of green roofs from the building owners. However, if only the cost of soft-landscaping was considered, the installation cost of an intensive green roof was estimated to at least double the cost of an extensive green (Townshend and Duggie, 2007). In this study, the installation costs were different among the intensive green roofs. The installation costs of the green roofs with the flowerpot design (SGT and SXV) were considerably lower than that of the green roofs with the garden bed design (APR, ASH, MHT, MTK, and SGK). Soil volume were one of the factors that could generally affect the cost of intensive green roofs (Townshend and Duggie, 2007). Therefore, the lower installation cost of flowerpot green roofs could be the result of the lower requirement of soil volume, which is normally lower than the garden bed designs. Moreover, additional loading could increase the installation cost. If a green roof was constructed on an existing building, more investment to upgrade the green roof structure would be needed to avoid exceeding the roof carrying capacity, therefore, possibly increasing the installation cost (Peck and Kuhn, 2003). Since flowerpot green roofs allowed an easier installation on existing roofs and needed few modifications of roof structure, they were usually the cheaper form of roof gardening (Proksch, 2011; Whittinghill and Starry, 2016). However, as the green roof increases in size, the installation cost per unit area became cheaper. This was consistent with the previous study of green roof installation cost in United States which showed that the cost depended on the green roof size and the cost per unit area decreased when the total size increased (The United States General Services Administration, 2011). In addition, the installation cost was also influenced by the ratio of hard- to soft-landscaping, size and maturity of trees, and vegetation types grown on green roofs (Townshend and Duggie, 2007).

Although all green roofs in this study were not constructed primarily for the provisioning service propose, the possible benefits in terms of food and goods from the vegetation could be estimated. In this study, the provisioning service values could be measured by two types of units: the number of plant species with the potential to provide foods and other goods and the monetary benefits associated with some of these food and goods items. A single plant species could provide several provisioning services. Edible plants were rarely found on the green roofs in this study, resulting in the low species richness. The edible plant products were not directly used, however, as the items were not sold. Several ornamental plant species found on the green roofs could be used as traditional medicines, although they were not really used by the stakeholders. To enhance provisioning services on a green roof, plant selection should be considered carefully to cover various types of provisioning benefits and the utilization of these possible provisioning services also have to be realized by the relevant stakeholders.

In this study, the total monetary benefits of edible and ornamental plants varied widely from 10% to 86% of the total installation cost. There was the possibility of higher provisioning service values on the green roofs if the monetary data of other utilizations were available and included in the total monetary benefits. Furthermore, the findings also suggested that the actual utilization of provisioning services of green roofs was still limited since most of the plants on green roofs were only used for ornamental benefits.

Originally, four use categories of vegetation, namely, edible, medicinal, ornamental, and other use plants, were included in the investigation of monetary benefits of provisioning services. However, only the monetary benefits of edible and ornamental plants could be identified. Therefore, these two types of utilization were selected as the representatives of the monetary values of the provisioning services on the green roofs in this study. Nevertheless, the production sale prices of vegetation in the reference report (Bureau of Agricultural Commodities Promotion and Management, 2017) did not cover all plant species found in this study. Thus, the costs of some plants were used to estimate the monetary benefits instead of their sale prices. Hence, the results of provisioning services in this study could not be compared directly with the values that were generally assessed from the production quantity and income in other studies (Zinia and McShane, 2018).

In this study, the major limitations of the estimation were the scarcity of available data required to calculate the cost and benefits of vegetation on green roofs in a tropical setting as in Thailand. The actual life cycle cost of green roofs would include the costs of the initial installation, operation and maintenance, and disposal of used materials (Feng and Hewage, 2018). However, the building owners and the people who are in charge of green roof maintenance did not want to reveal the cost of green roof maintenance. Furthermore, the disposal cost was not included in this study. Moreover, the knowledge about maintenance and life cycle of green roofs in Thailand was still deficient because the green roofs have been a rather new innovation in the country. The lifespan of green roofs is typically longer than conventional roofs and ranges from 40 to 55 years (Bianchini and Hewage, 2012). Green roofs in Germany could last as long as 90 years (Porsche and Köhler, 2013). It is unclear whether green roofs in the tropical climate would have a similar lifespan as those in the temperate zone, as plant growth and decomposition rates could be accelerated in the warmer temperatures.

Therefore, the outcome of this study signified the importance of basic information about green roofs in Thailand and elsewhere. Crucial information includes installation and maintenance costs throughout the lifespan of the green roofs and provisioning services and other environmental benefits, preferably as economic or monetary values. The lack of understanding about economic costs and benefits is one of the important barriers against the green roof development (Townshend and Duggie, 2007). If these green roof economic costs and benefits could be completely estimated, the actual net benefits that owners would obtain from their green roofs could be evaluated more accurately. The monetary values of green roof application are not only the easy communication way to make people understand more about the green roof benefits, but also a way for encouraging people to implement green roofs. Furthermore, these economic costs and benefits of provisioning services on green roofs, as well as other ecosystem services, can be used to create effective policies and incentives to promote green roofs in Bangkok, Thailand.

4.5.3. Cultural services: Potential in providing recreational and educational space

The results showed that the green roofs in this study could provide cultural services, mainly recreation and education. Most green roofs in this study, as well as most other green roofs in Thailand, were basically constructed for recreational purposes. People could access the green roofs and obtain benefits through recreational activities in the space provided. In contrast, people were not allowed to access and use the green roofs on SGK and SGT, and therefore the recreational services were not present.

Thus, accessibility should be prioritized to improve cultural services of green roofs. The green roofs which are open publicly could provide a better potential in recreational services. Nevertheless, safety and access limitations also need to be considered because the green roofs are commonly located on the private areas of public buildings (e.g. a department store and a hospital) or on private buildings (e.g. condominium). Therefore, the accessibility of green roofs could be differently managed depending on the building owner's perspectives. Proper strategies to support both accessible green roofs and safety should be considered. For example, some regulation for visiting and using green roofs could be determined, such as appropriate opening hours or allowing only building residents or clients as visitors.

The findings of this study indicated that green roofs have the potential to support cultural services, specifically recreational benefits. In addition, ASH and SGK were used to conduct learning activities, therefore, providing educational services to the participants who learned various environmental topics. However, the learning center for urban agriculture on SGK was closed in February 2017. Even though using green roofs for education benefits was still limited in Thailand, it was feasible to add facilities and activities to support relevant learning capacities, enhancing the value of educational services to green roofs.

Most green roofs could achieve the quantity and accessibility standards for green space, but some lacked some characters in quality standards, which could be classified as other ecosystem service types, including the ability to reduce air pollution, the ability of soil and water conservation, biodiversity conservation, and suitable plant selection. Although the capability of green roofs to provide cultural services was lower than other general green spaces, green roofs still provided some elements and attributes that were regarded as the important components of urban parks for recreation, such as accessibility, safety, seating, and shelter (Zhang et al., 2013).

In addition to recreational and educational benefits, other benefits can be classified as cultural services. Ko and Son (2018) studied seven types of cultural services served by urban green space in Gwacheon Republic of Korea and they included recreation, education, cultural heritage, social relation, health, religious, and aesthetic benefits. Langemeyer et al. (2018) found that urban green space in Barcelona, Spain could provide cultural services and other benefits which also extended into other issues such as nature experiences, physical recreation, community, and politics. Green roofs are also one type of urban green space; therefore, the other cultural services found in urban green spaces could be also discovered on green roofs. Green roofs could improve social relation of the people by conducting community garden for residents to participate together (Hamzah, Ja'afar, and Sulaiman, 2017). Rooftop gardens on the hospitals were used as rehabilitation areas for the patients' physical therapy, such as therapy walk (Davis, 2011). Therefore, it was possible that green roofs in Thailand could also have the potential to provide several kinds of cultural services. However, there were still a few studies about the cultural services on green roofs. Then, the other cultural services on green roofs should be investigated how to create the green roofs that could provide several kinds of cultural services because more cultural services discovered would possibly help the people to recognize the emphasis on green roofs and could lead to encouragement for green roof installation.

4.5.4. Supporting services: Diversity of meso- and macro-soil fauna

Substrate is obviously used as an important habitat and source of food for soil fauna; therefore, substrate condition is one of the important factors that can affect colonization and diversity of soil fauna. Generally, the soil conditions of the study sites were quite dry and weakly acidic. The percentage plant cover and leaf litter weight varied widely among the green roofs in this study, probably as a result from differences in the green roof design and maintenance. No relationship was found between the plant cover and soil fauna diversity, which was consistent with the previous findings by Rumble and Gange (2013) that plant cover did not correlate with soil microarthropod diversity on extensive green roofs. However, some investigations proposed that the diversity of roof soil arthropod was influenced by plant cover more than plant diversity (Schindler et al., 2011). Therefore, further study with more green roofs are needed to investigate the relationship between plant cover and diversity of soil fauna on green roofs.

Litter functions as a niche for soil fauna, influencing soil fauna diversity (Huot et al., 2018). Specifically, soil fauna use litter as food and suitable habitats (Yin et al., 2010). For example, the presence of epigeic earthworms in an unmanaged beech forest was correlated with the amount of litter (Campana, Gauvin, and Ponge, 2002). No relationship was found between the litter weight and soil fauna diversity on the green roofs in this study. Warren and Zou (2002) found no correlation between abundance of macro-soil fauna and amount of litter, suggesting that quality of litter might has more influence on soil fauna than litter quantity. Ilieva-Makulec, Olejniczak, and Szanser (2006) similarly reported that litter quality was an important factor influencing micro- and meso-soil fauna. Therefore, litter quality on intensive green roofs might be one of the factors that could affect soil fauna diversity and should be investigated in a further study.

Soil moisture and temperature were the important factors that have influences on biology, function, and community structure of soil fauna (Mandal, 2012). The findings indicated that only the soil moisture correlated with soil fauna. Moisture was a limiting factor for survival of many faunas, especially on green roof where various harsh conditions occurred and also had an effect on soil fauna activity. For example, soil fauna feeding activity would increase when soil moisture increased (Tao et al., 2016). Moreover, it could affect decomposition in soil and also the litter quantity and quality (Mandal, 2012); therefore soil faunas could eventually be influenced because of the changes in decomposition and litter. Soil moisture had a relatively higher influence on soil fauna diversity than other factors. A decrease in diversity and abundance of soil fauna living near soil surface, such as snail, and millipedes, was observed when the soil moisture decreased, even though the litter amount decreased (Coyle et al., 2017). The soil temperature did not correlate with soil fauna diversity in this study. The distribution, abundance, and survival of soil fauna, such as Collembola and Acari, in tropical forests were influenced by moisture and rainfall while there was no strong correlation between soil temperature and diversity of some soil fauna, such as Collembola (Deharveng and Bedos, 1993; Wiwatwitaya and Takeda, 2005; Pequeno et al., 2017). However, the occurrence of soil fauna differed among tropical home gardens according to seasonal changes and negatively correlated with soil temperature, which ranged from 27.3 to 32.3 °C in summer (Lakshmi and Joseph, 2017). On the other hand, in temperate zones, both soil moisture and soil temperature had significant impacts on population dynamics of soil fauna and the decrease of soil fauna diversity could be driven by increasing soil temperature (Choi et al., 2006; Pfingstl, 2013; Robinson et al., 2018). In this study, the investigation was conducted during a short period in the same season. Therefore, seasonal changes in soil fauna diversity could not be detected. Further investigations of seasonal dynamics in green roof ecosystems would require a longer study period as well as sufficient replications to provide more comprehensive results.

The diversity of soil arthropods on green roofs increased over time and they varied highly depending on several biotic and abiotic factors (Ksiazek et al., 2018). The community composition of low-mobility soil arthropod species was affected by local environmental conditions (Braaker et al., 2014). Therefore, in addition to being brought from plants and soil, it was possible that soil arthropods could settle in the green roof depending on environmental conditions. The average soil pH of the green roofs in this study (pH 6.3) was in the pH range between 2.9 and 7.6, generally preferred by arthropods (van Straalen and Verhoef, 1997), however, no correlation was observed between the soil pH and soil fauna diversity. Low pH in soil would affect plant growth, and then poorly produced litter would accumulate (Frouz, 2018). Litter of poor quality could have an adverse effect on soil fauna survival.

Ten soil fauna orders found on the green roofs in this study were also generally found in ground level gardens (Thompson et al., 2006; Cluzeau et al., 2012). Hymenoptera and Acari were observed on all green roofs in this study. The results showed that the number of individuals were considerably higher than the number of soil fauna orders. This is because of the social nature of ants (Hymenoptera) while mites (Acari) are usually found in ant nests (Eickwort, 2003). Soil fauna play the important roles in the ecosystem processes, including direct and indirect effects on biogeochemical cycling, decomposition rates, primary productivity, and other processes (Nielsen, 2019). For instance, Isopoda was a litter transformer that support litter fragmentation and Spirobolida was a decomposer. Hymenoptera could influence the modification of organic matter in soil and are sometimes considered as ecosystem engineers. Opisthopora could enhance carbon and nutrient mineralization in soil which eventually result in the promotion of plant growth (Nielsen, 2019). Furthermore, some soil fauna, such as Acari, were considered as important bioindicators of human activities including contamination, agriculture, and urbanization (Sophie et al., 2017).

APR, MHT and MTK were the green roofs providing the highest number of soil fauna orders. These three green roofs had continuous coverage substrate. On the other hand, the limited substrate of the flowerpot structure of SGT probably contributed to the low diversity of soil fauna. According to the Island biogeography theory, a higher diversity is found in a larger 'island' than in a small one (MacArthur and Wilson, 2001). As flowerpots were used as containers instead of directly growing vegetation in the substrate, these flowerpots likely function as islands with substrate suitable for colonization by soil fauna with low mobility. Therefore, continuous substrate of green roofs could have higher potential to provide habitat for various soil fauna orders than the green roofs with flowerpot design.

Furthermore, APR, MHT, and MTK also had more complex plant communities, composing of trees, shrubs, and herbs. Different growth forms of vegetation provided litter with different properties (Cepáková and Frouz, 2015), which could be preferred by a more diverse community of soil fauna. Although SGK had the continuous coverage substrate, the diversity of soil fauna was still low probably because of the limited diversity of green roof vegetation. Plant species can influence the abundance and diversity of macro-soil fauna (Loranger-Merciris et al., 2007) because different plant species provide different litter production and quality (Wardle et al., 2004). Therefore, green roofs with a lower diversity of vegetation might provide a lower diversity of soil fauna. The findings in this study suggested that designing green roofs for soil fauna conservation required continuous substrate and diverse vegetation growth form and species which were the ecological characters that enhance supporting services and subsequently support other ecosystem services (e.g. nutrient cycling and providing nutrients for plant growth in regulating services). However, in practice, having abundant soil fauna on the accessible green roofs might cause some negative impacts for the green roof owners and visitors, such as plant damage (e.g. thrips and mites), annoyance or injury to people (e.g. flies and mosquitoes) (Ebesu, 2003). Therefore, proper maintenance and management of green roofs is essential to reduce the impacts or prevent any undesirable consequences. In other words, beneficial and harmless soil faunas can be conserved while soil faunas with negative impacts would be controlled.

CHAPTER V

GREEN ROOF ECOSYSTEM SERVICES BASED ON A RAPID ASSESSMENT CHECKLIST

5.1. Rapid assessment checklist for ecosystem services on green roof

The developed rapid assessment checklist for ten ecosystem services on a green roof was composed of 46 proxy indicators: 33 qualitative and 13 quantitative indicators. Some indicators could be used for the assessment of several services. Therefore, five regulating services, including gas regulation, climate regulation, stormwater regulation, waste treatment, and pollination, were evaluated using 24 proxy indicators. To assess food provision (provisioning ecosystem service), 11 proxy indicators of the checklist were used. Three cultural services (aesthetic, recreation, and science and education) were estimated using 12 proxy indicators. Lastly, 12 proxy indicators of the rapid assessment were collected in order to evaluate the habitat provision as part of the supporting service.

5.2. Ecosystem service scores of different green roof structures

The ecosystem service scores calculated from the rapid assessment checklist are presented in the Table 5.1. All seven green roof study sites provided all of the four ecosystem service categories (regulating, provisioning, cultural, and supporting services), but to varying extents. The ASH rooftop received the highest score of total ecosystem services of 74 points, whereas SGT had the lowest total ecosystem service score of 48, while the average total ecosystem service score of all seven rooftops was 62 ± 9. The average scores for regulating and supporting services were the highest at 69 ± 8 and 68 ± 7, respectively. Lower scores were obtained for provisioning services (52 ± 13) and cultural service scores (57 ± 15). However, the scores for each of the ecosystem services were different among the green roofs included in this study.

For the regulating services, ASH had the highest score of 86 points while SGT had the lowest (59 points). SGK (rooftop farming) had the highest provisioning service score (82), whilst SXV had the lowest (36; poor). The cultural service score ranged from 79 points for ASH down to 27 points (poor) for SGT. Lastly, the supporting service score ranged from 79 points (ASH) to 58 points (SGK).

Cluster analysis divided the seven green roofs into two distinct groups based on their relative ecosystem service scores (Figure 5.1). The first group (APR, ASH, MHT, MTK, and SGK) were the green roofs that received a total ecosystem service score of more than 60 points (good and excellent performances in total ecosystem service provision). On the other hand, the second group (SGT and SXV) showed a total ecosystem service score of less than 60 points (intermediate and poor performances in total ecosystem service provision). The green roofs in the first group could obviously provide higher scores of regulating and supporting services than the second group. No green roof gained good or excellent scores in all four categories of ecosystem services (Figure 5.2).

Table 5.1 Scores for the green roof ecosystem services derived from the rapid assessment tool

Study site	Ecosystem service scores (total of 100)				
	Regulating	Provisioning	Cultural	Supporting	Total
APR	74	45	59	70	62
ASH	86	55	79	79	74
MHT	70	55	62	75	65
MTK	68	45	60	69	61
SGK	62	82	65	64	68
SGT	59	45	27	59	48
SXV	63	36	49	58	52
Average ± SD	69 ± 8	52 ± 13	57 ± 15	68 ± 7	62 ± 9

Note: The performance of green roofs for providing ecosystem services was interpreted from the ecosystem service scores as follows: 0–39, 40–59, 60–79, and 80–100 as a poor, intermediate, good, and excellent performance, respectively, in provision of ecosystem services.

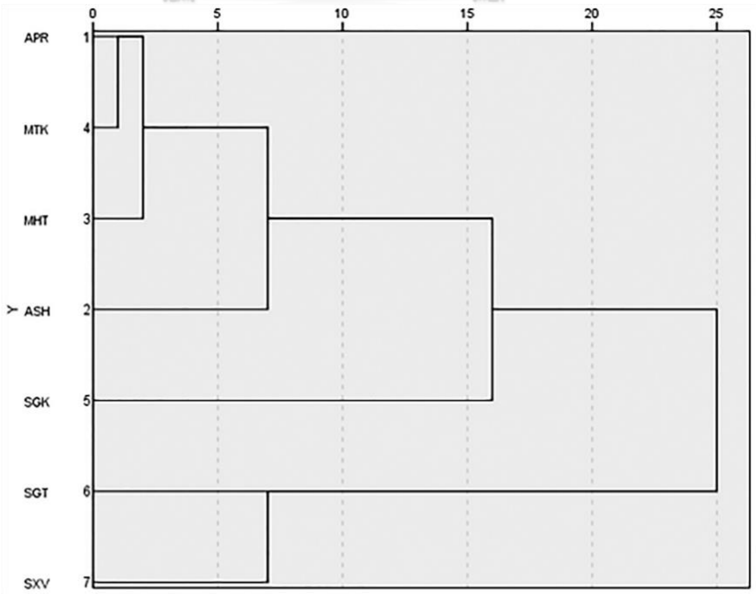


Figure 5.1 Classification of the green roofs based on the total ecosystem service values

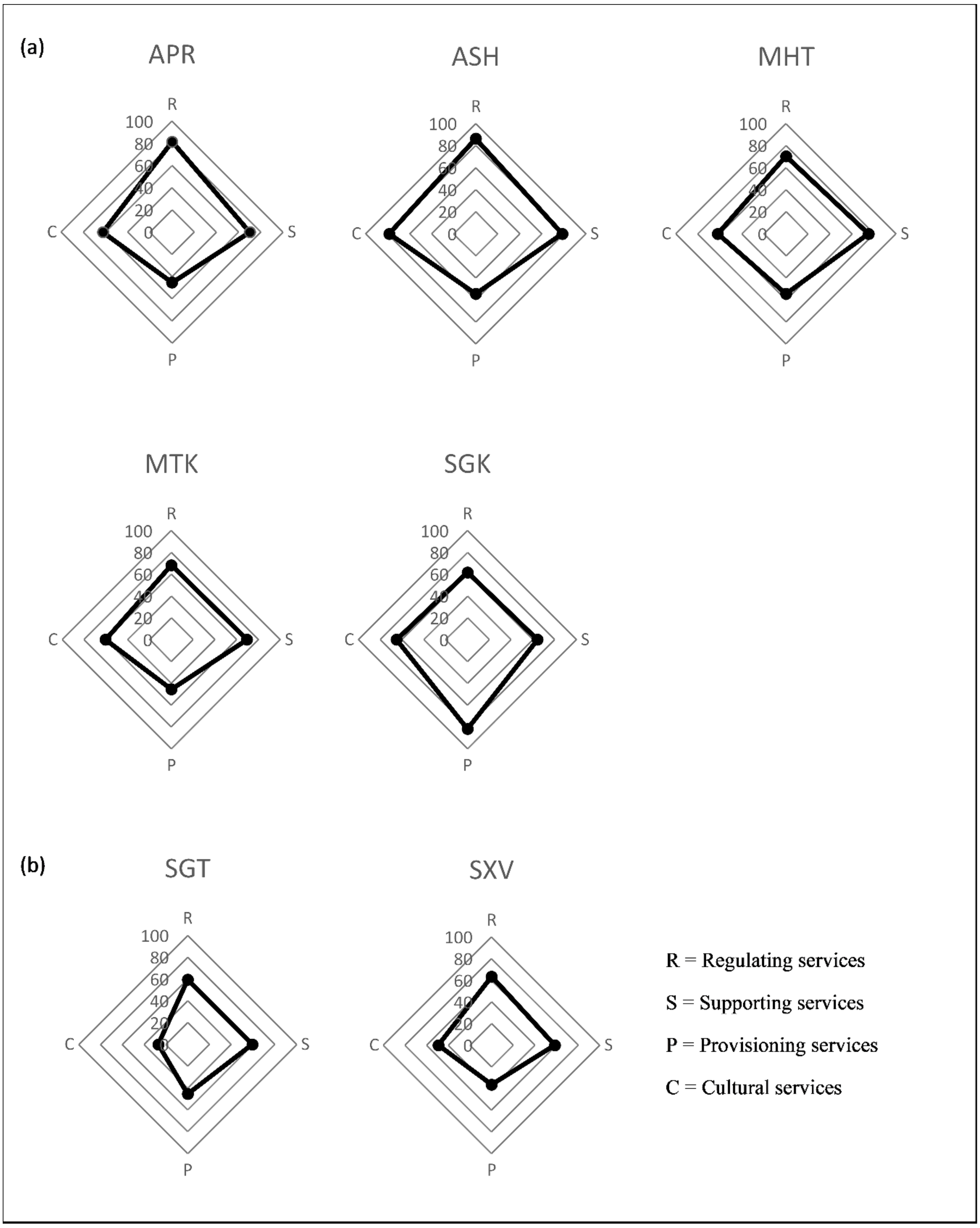


Figure 5.2 Radar chart of ecosystem service value on green roofs: (a) Green roofs with good and excellent performances in total ecosystem service provision, and (b) green roofs with intermediate performances in total ecosystem service provision

Furthermore, three pairs of ecosystem services showed significant positive correlations with good to strong relationships (Table 5.2), namely regulating and cultural services, regulating and supporting services, and cultural and supporting services. Positive correlations were also evident between provisioning, cultural and supporting services, although without statistical significance. On the other hand, regulating services correlated negatively with provisioning services but the relationship was not statistically significant.

Table 5.2 Correlations between ecosystem services on the green roofs in this study

		Regulating	Provisioning	Cultural	Supporting
Regulating	Pearson correlation	1	-0.447	0.770^{*}	0.883^{**}
	Sig. (two-tailed)		0.314	0.043	0.008
	N	7	7	7	7
Provisioning	Correlation coefficient	-0.447	1.000	0.447	0.592
	Sig. (two-tailed)	0.314	.	0.314	0.162
	N	7	7	7	7
Cultural	Pearson correlation	0.770^{*}	0.447	1	0.794^{*}
	Sig. (two-tailed)	0.043	0.314		0.033
	N	7	7	7	7
Supporting	Pearson correlation	0.883^{**}	0.592	0.794^{*}	1
	Sig. (two-tailed)	0.008	0.162	0.033	
	N	7	7	7	7

Correlation is significant at the * 0.05 or ** 0.01 level (two-tailed).

5.3. Ecosystem service tradeoffs and synergies on green roofs

The different ecosystem services provided by an ecosystem can influence each other (Turkelboom et al., 2015). Therefore, in addition to the factors mentioned above, the values of ecosystem services could also be affected by the relationships between services as shown by the correlations between proxy scores of ecosystem services on the green roofs. Two types of relationship found in this study were tradeoffs and synergies. Tradeoffs can be observed when one ecosystem service is increased as a result of the decrease in another ecosystem service (Rodríguez et al., 2006). The negative relationship between the proxy scores of different ecosystem services could represent the tradeoffs among ecosystem services. Positive relationships could represent synergies among ecosystem services, the opposite of tradeoffs (Howe et al., 2014).

A potential tradeoff between provisioning and regulating services was previously reported for green roofs. Harvesting for food production directly decreased the amount of carbon storage on the green roofs. Using fertilizers could enhance plant growth and food production but could adversely influence the runoff quality of green roofs (Czemiel Berndtsson, 2010). However, the tradeoff between regulating and provisioning services in this study was not statistically significant, probably because of the low number of study sites which included only one green roof constructed purposely for provisioning services (food production). Nevertheless, the tradeoff correlation between regulating and provisioning services was predominant among the relationships between ecosystem services (Lee and Lautenbach (2016). Moreover, a negative correlation between soil fertility and forage availability was found in a temperate forest (Chillo et al., 2018). Therefore, the ecosystem service tradeoffs in this study were consistent other general ecosystems. However, further studies with a higher number of study sites would be required for confirmation.

Potential synergies between regulating and cultural services, regulating and supporting services, and cultural and supporting services, were found on the green roofs in this study. A combination of vegetation species on green roofs can increase their survivability (Nagase and Dunnett, 2010)Therefore, green roofs with a diverse vegetation mix would likely perform their regulating services better than other green roofs with monoculture vegetation. Similarly, a greater vegetation diversity on green roofs in Spain was preferred by people (Fernandez-Cañero et al., 2013), showing the synergy and inferring that the aesthetic value in cultural services could be enhanced by adding plant species to green roofs. Low vegetation cover on green roofs can result in a low runoff retention and less support for fauna, resulting in lower habitat provision (Dunnett et al., 2008). Therefore, assuming the synergy between the regulating and supporting services, vegetation cover might be increased on green roofs and subsequently provide more regulating and supporting services. Tribot, Deter, and Mouquet (2018) proposed that there are links between the aesthetic value and ecosystem services, which are related to biodiversity. If the aesthetic value of green roofs is raised and more people appreciate the importance of green roofs, the public support for green roof construction would probably increase, eventually leading to conservation of fauna on the green roofs. Thus, cultural and supporting services can support each other.

The quality of urban life can be influenced by urban ecosystem services and then enhanced by locally generated ecosystem services (Bolund and Hunhammar, 1999). The more ecosystem services are provided, the better human life is. Therefore, the capability of green roofs for substantially serving the four main categories of ecosystem services should be considered in urban landscape design and management. Due to the tradeoffs between ecosystem services on green roofs, the ecosystem services could be limited in both the potential and number of service types. Nevertheless, tradeoffs and synergies among ecosystem services are not fixed, and the relationships can change in space and time because of ecological processes and policies (Bennett, Peterson, and Gordon, 2009). Therefore, management of green roofs should be considered wisely in order to mitigate tradeoffs or to enhance synergies. For instance, using biological fertilizers instead of chemical fertilizers or pesticides on green roofs can reduce the tradeoff between regulating and provisioning services by improving the storm water runoff quality without affecting the production yield. However, in practice, the management for improving the ecosystem service will depend on the perspective of the green roof's owner. This is because some limitations, such as limited resources, green roof structure, or the intended functions, will limit multiple ecosystem services as some services are probably not suitable or necessary from the owner's perspective. It is therefore imperative to reconcile the ecological requirements for green roofs with a high potential to provide ecosystem services and the applicability and usability for architectural design and overall maintenance.

5.4. Attributes of the rapid assessment tool

Currently no existing tools have been used to holistically evaluate ecosystem services on green roofs. Therefore, the current assessment tool was developed specifically for ecosystem service valuation at the landscape or local scale of green roofs, and so it should reflect the green roof ecosystem service values better than other general assessment tools.

The assessment tools should have measurability, replicable results, credibility, flexibility, and affordability (Bagstad et al., 2013). This rapid assessment was constructed using a composite indicator method (Alam et al., 2016). Therefore, the different units of ecosystem service value were quantified and transferred into the same unit through normalization. The ecosystem service scores were summed together and demonstrated in total scores and radar charts that were easily understandable even by non-specialists. In addition, the ecosystem service values were scored based on measurement and observation variables that were divided into different categories where the resulting scores could be clearly considered. For example, in this study, the assessment of green roof potential for carbon sequestration was scored using the green ratio and the two categories to be selected were 'high' (≥ 75%, 1 point) or 'low' (< 75%, 0.5 point). Additionally, the ability of a green roof to provide habitats was evaluated using the occurrence of perching habitats on a green roof into the two categories of 'high' (found, 1 point) or 'low' (not found, 0 point). Assigning a score by category is a common method for a rapid assessment that probably reduces the variability of scoring and so the error of measurement can be decreased (Fennessy et al., 2007). Therefore, this assessment tool could create replicable and robust results of ecosystem service values, although validation was still required for more fully accurate outputs. The accuracy of ecosystem service values depends on the quality of reference studies (Brenner et al., 2010). Accordingly, the proxy indicators in this rapid assessment were carefully selected based on the suggestions or conclusions in previous research and recommendations in the expert-based guidelines.

The assessment tool should be applicable in various contexts. Even though generic indicators were used in the rapid assessment, the indicators were able to estimate the preliminary ecosystem services of the selected green roofs. Moreover, because international standards have been used as the criteria for the indicators, the rapid assessment is not limited for use only in Thailand but could also be conducted in other countries. Using the assessment tool does not require specialized skills, and so it can be used by both specialists and non-specialists. Specialists, who have technical knowledge that is relevant to green roof and ecosystem services, can use the tool as preliminary indicators for the types and amounts of green roof ecosystem services. Non-specialists, such as building owners, officers, or gardeners, can also easily participate in the simple assessment process and understand the simple proxy scores of ecosystem services. However, the green roofs ecosystem services in this study were evaluated by the researchers only because the usability by specialists was the main focus of the first version of the checklist tool. Therefore, in further studies this assessment checklist tool should be tested with non-specialists in parallel with specialists to confirm that it can be practically used by non-specialists.

This assessment was a preliminary estimation of ecosystem services using a number of checklist items that were easy to evaluate and required a small amount of time and effort to conduct. Fennessy et al. (2007) proposed the definition of rapid assessment as a process that is conducted by no more than two people and does not exceed a half day total in the field and another half day for preparation and analysis. Hence, this assessment tool achieved the definition of a rapid assessment because the users spent only half day for the checklist and less than half day for the analysis. Apart from that, this assessment also had the desirable attributes that were different from the conventional tools, such as low technical knowledge, manpower, and cost requirements, as seen in Table 5.3, and so the participation of people in the evaluation process could be encouraged. Overall, the features and requirements of this checklist were similar to other rapid assessment tools, such as RAWES and TESSA.

This assessment tool could be applicable to the management and improvement of existing green roofs. The ability of a green roof as a provider for ecosystem services can be indicated by the ecosystem service score from the assessment. Therefore, each owner can realize what are the outstanding and the poor services of their green roof, and then can manage and maintain their green roofs appropriately in order to improve the poor services and sustain the good ones. Apart from that, the assessment tool can also be used for designing green roofs with a focus on ecosystem services. In the future, it can be applied as a collective learning green roof game for the purpose of promoting green roofs and their ecosystem service to the public.

Table 5.3 Comparison of key attributes of different ecosystem service assessment tools, derived from an overview by Peh et al. (2013) and Waage and Stewart (2008)

Assessment tool	Description	Scope	Intended user(s)	Data requirement	Academic knowledge	Time	Manpower	Cost	Reference
Rapid assessment checklist for green roofs	Checklist tool for estimating ecosystem services on green roofs	Landscape (Local)	Specialists/Non-specialists	Low–High	Low	Low	Low	Low	This study
Corporate ESR	Qualitative tool for identifying, prioritizing, and assessing impacts of ecosystem services	Landscape-global	Specialists/Non-specialists	Low	High	Low	Low	High	Hanson et al. (2012)
InVEST	Computer-based tool for ecological production and subsequent economic valuation	Landscape-global	Specialists/Non-specialists	Low–High	High	Interme diate-High	Low	High	Sharp et al. (2016)
RAWES	Checklist tool for assessing 37 ecosystem services provided by a wetland	Landscape	Specialists/Non-specialists	Low–High	Low	Low	Low	Low	McInnes and Everard (2017)

Table 5.3 (continued)

Assessment tool	Description	Scope	Intended user(s)	Data requirement	Academic knowledge	Time	Manpower	Cost	Reference
TESSA	Suite of tools used for evaluating and monitoring ecosystem services at a site scale	Landscape	Specialists/Non-specialists	Low–High	Low	Low	Low	Low	Peh et al. (2013)

5.5. Comparison between the direct measurement and the rapid assessment of ecosystem services in this study

The direct measurements of green roof ecosystem services could provide the outputs which offer more accurate and precise values of ecosystem services than the rapid assessment. Multidisciplinary methods were used for the assessment of ecosystem services on the green roofs. Each service could be evaluated by different methods depending on the suitability and availability. Regulation, provisioning, and supporting services were mostly measured as material benefits; therefore, the quantification of these services was relatively easier and less complicated than the assessment of non-material benefits of cultural services. For example, in this study, the amount of carbon storage was used to measure the capacity of green roofs to regulate greenhouse gas fluxes, as one of the regulating services, and the order richness of soil fauna was conducted to evaluate the ability of habitat provision, one of the supporting services. The estimation of economic value of the possible production from vegetation on the green roofs were used to evaluate provisioning services. This is because ecosystems usually provide provisioning services which are products that can be traded, such as wood, vegetable, or fruits (Gradinaru, 2013). However, in this study, there was a lack of the actual utilization and data about prices of the products on green roofs, it resulted in the difficulty for completely evaluating the actual monetary benefits of the vegetation on green roofs in terms of provisioning service. On the other hand, cultural services are usually non-material benefits (Satz et al., 2013), and then the results in this study were presented in the qualitative and descriptive data of the utilization types found on green roofs and the achievement of green space standards. Because of the different units of ecosystem services, it was difficult to aggregate their values to determine the total ecosystem service values and compare the potential in provision of different services. Although the results from direct measurement of ecosystem services can be transferred into monetary values before aggregating to the total ecosystem service potential (de Groot et al., 2012), in practice there are some limitations in this approach that should be carefully considered (Baveye, Baveye, and Gowdy, 2013). For example, the ecosystem service values estimated by economic valuation are not always performed in monetary terms, but they are preferably expressed in the benefits of ecosystem services to society (well-being) and business profitability (Swedish Environmental Protection Agency, 2018). Moreover, due to the complexity of ecosystems, biophysical and socio-cultural benefits cannot be fully captured by monetary estimation (Schröter et al., 2014; Vačkář et al., 2018).

The rapid assessment checklist was constructed using the framework of Ecosystem Services Composite (Alam et al., 2016) and the results were presented as the scores for individual and total ecosystem services of green roofs, thus avoiding the aggregation issue of different value units. Although the accuracy and precision of results from the assessment checklist could be compromised by the use of proxy indicators, the efficacy of the checklist would be compensated for by the reduced time and effort required to conduct the assessment as well as the ease of use and understanding for the stakeholders involved. Therefore, to improve the accuracy of the ecosystem service estimation, validation of the assessment tool should be conducted in the future to increase its reliability and sensitivity for evaluating the ecosystem service values. If required, more intensive and extensive methods could be added.

CHAPTER VI

PERCEPTION OF PEOPLE IN BANGKOK ON GREEN ROOF ECOSYSTEM SERVICES

6.1. General information of respondents and their experiences about green roofs

The respondents of the questionnaires were university students, workers, and experts. The analysis of socioeconomic characteristics showed that most of the respondents were female (Table 6.1). The major type of the participants were the university students in the 15-20 years-old age group and most of them were studying at a bachelor's degree level, with mostly between 5,000-10,000 baht monthly income. The workers were mostly 21-30 years old with a bachelor's degree or higher than a bachelor's degree. Their work incomes were mostly between 10,000-20,000 baht per month. Home and condominium were the most popular residence types of the respondents in this study.

Table 6.1 General information of the respondents

Socioeconomic characteristics		Students (n=259)	Workers (n=90)	Experts (n=5)
Gender (n=349)	Male	64	31	2
	Female	195	59	3
Age (n=349)	15-20	164	0	0
	21-30	92	70	2
	31-40	3	13	3
	>40	0	7	0
Education level (n=349)	Bachelor's degree student	231	0	0
	Graduate student	28	5	0
	Bachelor's degree	0	40	0
	Higher degree	0	45	5
Monthly income (n=349)	<5000	83	1	0
	5000-10000	146	0	0
	10000-20000	25	44	0
	20000-30000	3	30	0
	30000-40000	1	14	0
	>40000	1	1	5
Residence type (n=349)	Home	82	25	0
	Town house	45	14	0
	Condominium	82	33	5
	Other types	50	19	0

Overall, 44% of the respondents (the university students, workers, and experts) said that they knew the definition of a green roof. The workers showed a higher recognition of green roof (53%) than the university students (41%). Some respondents confused the definitions of green roofs, specifically the terms used in architecture and other disciplines or situations. For example, there was an environmental project called “Green roof” in Thailand that was about creating roofs using recycled UHT milk boxes (The Momentum Team, 2019). Therefore, some misunderstanding existed regarding the definitions of green roofs. The results also revealed that there were more green roofs at the university or workplace that the respondents went to (31%) than their residences (11%). Nevertheless, some respondents said that they did not know if there was a green roof at their residences and university or workplaces.

Only 28% of all respondents that had experience of visiting or using green roofs. Similar percentages of university students and workers who have visited or used green roofs. The types of their utilization on green roofs included using as a recreational area, an exercise area, a shortcut walkway between buildings and other uses, e.g. using a green roof as a research study site. Most of the respondents used green roofs every month at the frequency between one to 10 times per month. The average usage frequency was three times per month. However, some respondents indicated that they rarely used green roofs because it was difficult to find green roofs.

On the other hand, 72% of all respondents have never visited or used green roofs before. The reasons provided were that there was no green roof at the buildings they have visited, or the location of green roof was too difficult to find and enter. Other reasons were the fact that they did not know what a green roof was, whether there was a green roof in the building they visited or not, and where was the location of a green roof in the buildings. Apart from that, the lack of facilities on green roofs also affected the decision not to visit a green roof by some respondents.

6.2. Perception of people on green roofs in Bangkok

From the survey, the most recognized benefits of green roofs in Bangkok were increasing green space in the urban area (20%), changing abandoned rooftops into the useful area (18%) and enhancing aesthetic value and helping people in the urban area to get closer to nature (16%). Apart from that, the respondents also shared the opinions that green roofs could be useful in decreasing the building temperature and energy usage. Some of them suggested that solar cells should be installed on the green roofs to save the building electricity. Moreover, in their perspectives, green roofs could be used as a habitat for animals, a recreational area as well as a rooftop agriculture area. They thought that if rooftop farming was installed, the owners might get more income from the rooftop production. Moreover, they thought green roofs were the ecosystems that could be created on the building. Therefore, they inferred that green roofs might help to raise people’s awareness about the environment issues. Furthermore, most of the respondents also thought that buildings with a green roof were more attractive to customers than buildings without a green roof.

The disadvantages of green roofs that were frequently mentioned by the respondents were high costs for construction and maintenance (21%), the problem about moisture of the rooftop (21%), the problem about building structure and bearing capacity (18%), and drains that might be clogged with soil (17%). Apart from that, some respondents were worried about slow growth of green roof vegetation because of limitations on root growth and harsh conditions on green roofs. Moreover, some annoying animals, such as soil fauna and insects, could be found on green roofs and might cause dirtiness and diseases. Some respondents were also concerned about safety, such as accidents from fallen branches on the green roofs. They were also afraid that crimes might happen on green roofs if there was a lack of supervision.

Thirty-four percent of all respondents said that the high cost for installing and maintaining green roofs was the most important limitation of green roof construction. This was followed by unsuitable building structure and bearing capacity for green roof construction (29%) and lack of knowledge about green roof construction (23%). While other limitations were about accessibility, vegetation selection, and difficult management. Some green roofs were located on the area that was difficult to access or only building insiders were allowed to use green roofs. Apart from that, there were the respondents who emphasized the management and maintenance of green roofs. They were afraid the green roofs would be abandoned if there was no proper management and constant maintenance. Some of them worried about the unexpected problems that might happen after green roofs were constructed. One respondent shared an opinion that the existing green area at the ground level should be maintained or improved rather than installing green roofs.

Regarding the issue of green roof construction, the respondents were asked about the factors necessary for decreasing the limitations and supporting green roof construction. The respondents asked for experts to educate them about green roof knowledge (26%) and a policy for attracting people to have interest in green roof construction (23%). For example, tax deduction for entrepreneurs who have buildings with green roofs could be used as an incentive to promote green roof construction. Moreover, the respondents also thought that it would be possible for constructing green roofs at government offices as green roof case studies (22%). Apart from that, some respondents also proposed that the government should set the regulation or law which requires a green roof on a new building. The respondents also asked that the government support some cost of green roof construction. Furthermore, they suggested that the green roof related organizations or experts should provide green roof design ideas and plans. Furthermore, the important knowledge about structural engineering and landscape architecture should be shared with public.

6.3. Priority on green roof ecosystem services in Bangkok

Table 6.2 shows the priority of ecosystem services on green roofs that were ranked by 349 respondents and five experts. In the perceptions of university students and workers, gas regulation and climate regulation were the highest ranked ecosystem services while education was the lowest type according to the respondents. In the expert perception, climate regulation was the most focused green roof ecosystem services and it was followed by recreation and gas regulation services, respectively. While habitat and aesthetic information provision were ranked in the same priority. Pollination service was proposed as the least important ecosystem services. The results also presented that services in regulating services were chosen as the most important ecosystem services categories and they were followed by supporting, cultural, and provisioning services, respectively.

Table 6.2 Rank of ecosystem services that prioritized by respondents and experts

Ecosystem services	Rank in each group		
	Students	Workers	Experts
Gas regulation	1	2	3
Climate regulation	2	1	1
Waste treatment	3	3	4
Stormwater regulation	4	5	8
Habitat function	5	6	6
Recreation	6	9	2
Aesthetic information	7	8	6
Pollination	8	7	10
Food provision	9	4	5
Education	10	10	9

The university students and workers were asked to rank their preferences of ecosystem services and the average scores of the ecosystem services are presented in Table 6.3. The ecosystem service preference of the university students and workers were significantly different in gas regulation, waste treatment, pollination, and food provision. Gas regulation and waste treatment were rated by the university students as more important services than by the workers. On the contrary, the workers significantly gave more emphasis on pollination and food provision with higher scores than the university students.

Table 6.3 Difference of ecosystem service preferences between the university students and workers

Ecosystem services	University students		Workers		t	Sig.
	Average score	S.D.	Average score	S.D.		
Gas regulation	7.423	2.891	6.144	3.347	3.221	0.002*
Climate regulation	6.968	2.635	6.400	2.804	1.728	0.085
Stormwater regulation	5.368	2.950	5.500	3.399	-0.328	0.743
Waste treatment	6.336	2.721	5.933	2.530	-3.529	0.000*
Pollination	4.874	2.417	5.400	2.722	2.802	0.005*
Habitat function	5.265	2.145	5.478	2.567	-0.704	0.482
Food provision	4.419	2.645	5.667	2.824	-3.774	0.000*
Aesthetic information	4.874	3.141	5.000	2.579	-0.376	0.707
Recreation	5.016	2.917	4.856	2.717	0.456	0.649
Education	4.336	2.349	4.767	2.756	-1.322	0.189

Note: * p-value<0.05

6.4. Decision for green roof construction

More than 80% of the respondents wanted to a green roof constructed at their residence to increase the green area if there were enough space (Figure 6.1). More than 90% of the respondents wanted their university or workplace to construct more green roofs. Most of the respondents (92%) said that they would construct green roofs if they were building owners who could make the decisions. The respondents gave the reasons for and against green roof construction (Appendix K). Most of the respondents focused on the benefits of green roofs, especially environmental benefits, as the deciding factor for construction of green roofs. The respondents slightly preferred construction at their schools, universities, and workplaces to their residences. They thought that if they had a green roof at their residences, they would have needed to pay a high cost for installation and maintenance, which could be time-consuming. However, some respondents shared their opinions that they decide not to construct green roofs Mainly because of limitations of green roof and cost for construction and maintenance. Some of them also thought that green roofs were not necessary in the urban area because there was already enough green space at a ground level.

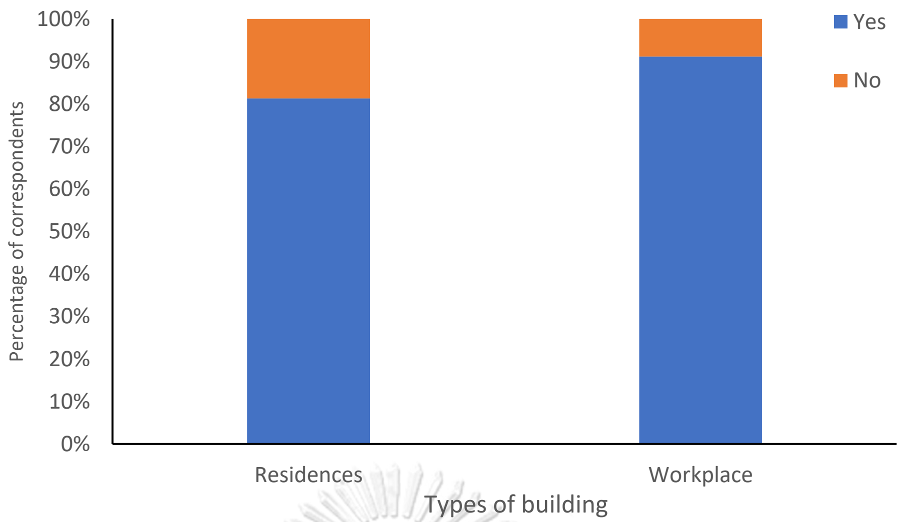


Figure 6.1 Relative proportion of the correspondents who answered whether they would decide to construct a green roof at their residence or workplace

The relationships between socioeconomic characteristics as well as the experience about green roof and the interest of green roof construction were studied. Significant relationships were found between the interest of green roof construction at residences and education level (Pearson Chi-square = 17.829, Sig. = 0.000 <0.05), and monthly income (Pearson Chi-square = 23.208, Sig. = 0.000 <0.05) (Table 6.4). The decision for constructing green roofs at universities or workplaces was significantly associated with the experience of visiting or using green roofs (Pearson Chi-Square = 9.101, Sig. = 0.003 <0.05). Lastly, the experience of visiting or using green roofs also had a significant association with the desire for installing green roofs if the respondents were building owners (Pearson Chi-square = 6.748, Sig. = 0.009 <0.05).

Table 6.4 The relationships between socioeconomic characteristics and green roof experience and the interest of green roof construction

Factors	Residence		Workplace		Their building	
	Chi sq.	Sig.	Chi sq.	Sig.	Chi sq.	Sig.
Gender	0.436	0.509	0.143	0.705	0.516	0.473
Age	6.941	0.074	5.202	0.158	3.731	0.292
Education	17.829	0.000*	0.355	0.949	6.077	0.108
Income	23.208	0.000*	3.971	0.554	3.189	0.671
Green roof visiting	2.507	0.113	9.101	0.003*	6.748	0.009
Knowing about green roofs	0.965	0.326	3.047	0.81	0.256	0.613
Residence type	0.678	0.878	1.035	0.793	2.312	0.510

Note: * p-value<0.05

6.5. Expert perception on green roof ecosystem services in Bangkok

Five experts who have experience in green roof design, construction, and management, or have ecological knowledge about urban ecosystems, participated in this study. Three architects, one engineer, and one biologist shared their perspectives on the green roof technology regarding the general characteristics, ecosystem service provision, and limitation and suggestion of installation aspects. Green roofs were originally created for saving building energy. One of the architect interviewees noted that green roofs for environmental purposes were constructed after the climate change issue was emphasized. Green roofs were included in the green infrastructure that was one of several strategies for climate change adaptation. Another architect who was interviewed explained that green roofs should help create a better environment in addition to saving building energy. The definition of green roofs was not limited to a rooftop garden but also extended to the use of flowerpots on a rooftop or a balcony. However, the effectiveness of functions in both architecture and ecological aspects would be different. While solar rooftops were normally constructed for energy generation, they could be classified as green roofs if they could help to provide shade and decrease heat of buildings. In other countries, green roofs were usually composed of various specific structure, such as drainage, root and waterproof barrier, and insulation. However, most of green roofs in Thailand were not designed specifically at the beginning and some green roofs would lack some structural layers. Some green roofs were installed afterwards and thus their design and management plan would need to be adapted to avoid the possible problems that might occur.

The popularity of green roofs in Thailand was still limited. One of the architects stated that the general public only focused on the usage of the building areas and still did not recognize the importance of the green roofs. Therefore, green roofs in Thailand have not yet gained much attention even though there was a growing popularity of green roofs in several other countries. Other interviewees, including the other architects, the engineer, and the biologist, thought that it was just a beginning stage of green roofs in Thailand and the possible barriers for green roof adoption were high construction and maintenance costs. However, the green roof technology in Thailand would possibly increase because people nowadays had more awareness about environmental issues. Moreover, due to a decrease in green space and an expansion of urban areas and high-rise buildings, the need of green roofs was probably higher in order to increase green spaces in Bangkok and other large cities.

All interviewees recognized that green roofs could provide ecosystem services that could solve the environmental problems in Bangkok. However, the performance of green roofs could be limited by the small area and high construction and maintenance cost of green roofs. Apparently, all experts highly emphasized climate regulation and gas regulation as well as recreational benefits.

The experts shared their perceptions on the limitations of green roof application in Thailand, especially their concerns about the high cost of installation and maintenance. However, one architect stated that actually the additional costs for green roof construction were not necessarily higher than conventional rooftops. In addition, the experts also mentioned that the collaboration of the multidisciplinary specialists, particularly a biologist or botanist, in the green roof design and management process was needed in order to create the preferable green roofs in both structural and ecological aspects. Moreover, some strategies for promoting green roofs in Thailand were suggested. The relevant organizations, such as the government, universities, institutions, and companies working on environmental and urban ecosystem issues, should be responsible for promoting green roofs. Both technical knowledge about green roof and financial incentives, such as tax deduction, provision of some installation costs, should be supported and offered. Furthermore, the experts also proposed some examples of the projects for green roof supports. A regulation or policy about installation of a green roof on the new building should be created. Moreover, the demonstration of benefits that the green roof owners would receive directly could help to encourage people to install green roofs. For example, conducting ecotourism on green roofs might provide income to the building owners and educational and environmental values to the public.

6.6. Understanding and interest of green roof installation in Thailand

More than 50% of the respondents in this study did not know green roof technology. Moreover, there was some confusing and misunderstanding the definition of green roofs. There were only a small number of people who had experience of visiting or using green roofs. It might result from several reasons. Some people could not indicate the appearance of green roofs because they did not know what a green roof was. Then, they also did not know whether there was a green roof in the building they visited or not, and where was the location of a green roof in the buildings. Apart from that, there was no green roof at the buildings they have visited. Some buildings had the green roofs, but it was difficult to find and access green roofs. Lack of facilities on green roofs also affected the decision to not visit the green roof of some respondents. The role of green roofs in people perception was mainly about increasing green space in Bangkok. However, the role of green roofs in terms of environmental benefit provider was poorly recognized.

Nevertheless, the findings revealed that there is a positive trend towards green roof construction since most respondents showed interest in having green roofs installed at their residence or their university and workplace. Due to the requirement of maintenance and investment costs, the respondents preferred the installation of green roofs at the university and workplace to their respective residences. The results also showed that they would agree to construct a green roof on the building if they were a building owner and had the power to decide whether they build a green roof or not. Interestingly, the education level and monthly income of people were the factors that influenced the decision on green roof construction at their residence. Education level could affect the favorite and attitudes toward green roofs (Fernandez-Cañero et al., 2013). Moreover, knowledge and cost seemingly are the important factors involved in the ability to install green roofs at their home. Financial support and technical knowledge were the major expected incentives that people need for encouraging their green roof installation. (Kalantari, Ghezelbash, and Yaghmaei, 2016). The experience of visiting and using green roof was correlated with the interest for green roof construction at their university and workplace as well as in case if people were building owners. This might be because people who have ever visited green roofs presumably had more awareness of the green roof benefits. According to Everett (2019), lack of experience in using and visiting green roofs can hinder green roof implementation. Therefore, the experience of green roof application was the important factor for encouraging the green roof adoption, especially the green roofs at the university and workplace. Additionally, some other behavior characteristics were also related to the interest of green roof installation, including the presence of a garden at home, interest in gardening, and perception on urban environment improvement (Fernandez-Cañero et al., 2013). Therefore, the investigation of the relationships between the socioeconomic and some behavior characters and the interest in green roof installation would be informative for developing a policy for green roof adoption in Thailand and elsewhere.

6.7. Preference for green roof ecosystem services

The results revealed that regulating services (i.e. gas regulation, climate regulation, stormwater regulation, and waste treatment) were ranked as the higher priority in comparison with other ecosystem service categories (i.e. provisioning, cultural, and supporting services) by both groups of the respondents. Gas regulating service was given the first priority of ecosystem services provided by green roofs in Bangkok. According to the Office of Natural Resources and Environmental Policy and Planning (2016), the five environmental issues in Bangkok, including global warming, solid waste, wastewater, air pollution, and lack of green spaces, were emphasized. Those regulating services could be used to solve or mitigate the important environmental issues in Bangkok. For example, gas regulation helps mitigate the urban heat island effect and vegetation on green roofs helps decrease air pollution. Then, the respondents might think that those regulating services were more significant than other services while educational service was ranked as the last priority. Green roofs, both intensive and extensive types, can be used as educational spaces to support the architectural and scientific knowledge, research, and experiences; however, the utilization of educational services was low (Kovács, 2017; Ko and Son, 2018). In Bangkok, Thailand, there are also the green roofs that provide community gardens and learning spaces, especially urban farming, such as Tarareanake Go Green Condominium, the Health Promotion Foundation, and Laksi District Administration Office’s buildings (Boossabong, 2018). Nevertheless, educational activities in general were still rarely found on the green roofs in Bangkok. Thus, this might lead to less awareness of educational services on green roofs in people’s perception.

However, different types of green roof stakeholders had different perspectives in the priority of ecosystem services. In this study, the university students put more emphasis on gas regulation while the office workers gave significantly more importance to climate regulation and food provision, probably as a result from differences in the knowledge and experiences in green roof utilization between these two groups. The university students were likely more engaged with environmental concerns through their study while the workers also thought about the services which could serve human needs, the food provision. Nevertheless, in addition to the university students and workers who could be the representative of visitors, green roof experts were also one of the important stakeholders. The green roof experts played various roles in green roof application, such as a designer, a builder, or a consultant of construction. Hence, the perception on green roof ecosystem service priority of the experts were also investigated. Surprisingly, the experts also emphasized the cultural services in addition to the services involved in environmental issues. Therefore, intended functions of green roofs in Thailand, which mostly are recreation and aesthetic value, were considered as the high priority in experts' perception.

The outcomes from investigation of green roof ecosystem service priority could be used for green roof design, construction, and management in order to provide the preferable services. For example, in green roof ecosystem service assessment process using ESC, the variables could be weighted differently based on the priority of green roof ecosystem services. Then, the results from the assessment would be more specific in accordance with the preference of each site and could satisfy human needs in terms of ecosystem services.

6.8. Possible obstacles for green roof construction in Thailand

The major obstacles for green roof construction in Thailand could be classified into two main issues, namely financial concerns and limited green roof knowledge, which were similar to that of other countries. The obstacles most often mentioned by the respondents in this study were high costs for construction and maintenance. According to Shafique et al. (2018), high construction costs were the most influential factors that hinder green roof implementation; however, the cost varied in different countries depending on several factors, such as green roof type, material, and labor cost. In Washington, DC, the extensive green roof cost were 27% more than the traditional roof construction (Niu et al., 2010). The cost for extensive and intensive green roof installation in Hong Kong were 400 to 1,000 HK$/m^2 (average 500 HK$/m^2) and 1,000 to 5,000 HK$/m2 (average 2,000 HK$/m^2), respectively (Townshend and Duggie (2007). In addition to the installation cost, the maintenance cost is a required long-term cost (Zhang et al., 2012). Green roofs suffering drought conditions need both irrigation and fertilization to provide the optimal services; moreover, in order to sustain and extend their lifespan, green roofs should be maintained properly by inspecting vegetation, substrate, and drainage (Shafique et al., 2018). Due to the low maintenance requirement of extensive green roofs, the recurrent costs of extensive green roofs are generally lower than that of intensive green roofs. In Hong Kong, the costs were approximately 0.8 to 2.25 HK$/m^2/year for extensive green roofs and 6.5 to 44 HK$/m^2/year for intensive green roofs (Townshend and Duggie, 2007). Unfortunately, there was no published data and information about green roof construction and maintenance costs in Thailand, but the results from this research indicated the most influential obstacles of green roof implementation were the high costs in construction and maintenance.

Some problems that might occur after green roof was constructed were mentioned by the respondents as concerns for green roof maintenance and management. Moistness from roof leakage was one of the challenges for green roof application; however, this issue could be avoided by installing green roof components and layers properly on the rooftop (Shafique et al., 2018). People were also afraid that the green roof weight would exceed bearing capacity of the building and probably result in the structural failure of building. This finding is also consistent with the study of barriers for applying extensive green roof on the existing building in Hong Kong and the weak loading of building structure was ranked in the top ten (Zhang et al., 2012). Loading capacity of the building is the main limiting factor and it was suggested that the building should be supported double or triple weight of the proposed green roof construction in order to bear the weight of overflow stormwater (Trepanier et al. (2009). Then, a structural engineer is needed to participate in green roof application and provide consulting for installation. Apart from that, due to the character of green roofs in Thailand that are rooftop gardens and usually use soil as the growing medium, a clogged drainage by soil was the important issue that could hinder the implementation of green roof. However, this issue rarely happens if the green roof structures, especially a filter layer, were properly installed. The filter layer is used for protecting the drainage layer from clogging by any fine particles (Nophadrain BV, 2019).

Apart from that, some safety issues arose during the interviews. Some people worried about the accidents of falls from the green roofs. However, the safety issues were normally included in the main factors that have to be considered in the design and planning process (Hui, 2010). Then, the collective fall protection, such as barriers, guard-rails, and toe-boards would be installed on the green roofs (Nophadrain BV, 2019). Due to the function of green roofs as habitat providers for animals, facilitation of disease transmission from any annoying animals was concerned, nevertheless, this possible negative effect of the green roofs could be mitigated by the proper maintenance (Fernandez-Cañero and González-Redondo, 2010).Furthermore, vegetation growth on green roofs was also considered. Then, to improve the vegetation growth, enhancement of organic material could indirectly increase plant growth (Nophadrain BV, 2019). Köhler and Clements (2013) also suggested that pruning plants should be done for mulching, and then it could be resulted in the increase of plant growth.

Moreover, the lack of knowledge about green roof design, construction, and maintenance was possibly one of the important barriers for enhancing green roofs in Thailand. Then, several difficulties of green roof management were indicated by the participants in this study. For example, plants had to be selected deliberately to survive in harsh conditions on green roofs; therefore, it would be better for green roof design and management if people have knowledge about plant species and their characteristics. According to Shafique et al. (2018), the researchers indicated that multidisciplinary collaboration should be encouraged for the green roof application and management.

In addition to provide environmental benefits, green roofs were also used as the strategy for increasing green space in the urban area. However, this study showed an unexpected result. Misunderstanding about the need of green area in Bangkok was found. Some people shared their opinion that there was enough green area in Bangkok already; therefore, green roof construction was not needed. Contrary to their view, actually the green area in Bangkok was still a limited number of 6.70 m^2 (Environment department of The Bangkok Metropolitan Administration, 2019) and less than the international standard of 9 m^2 per person (World Health Organization, 2010). Thus, this finding showed that correcting misunderstanding and transferring of knowledge and information about green area to the public is still required in order to encourage green roof application in Bangkok, Thailand.

In summary, most respondents showed their positive attitude towards green roofs. They could recognize several environmental benefits and ecosystem services provided by green roofs. Regulating services were the most important ecosystem services mentioned by all groups of respondents. Moreover, they also preferred to see more green roofs installed at their university and workplace, reflecting a positive trend in recognition of the significance of green roofs. Nevertheless, some difficulties for green roof application were also highlighted, such as constraints of green roofs, high construction and maintenance cost, and lack of green roof knowledge. The expert respondents also suggested the need for collaboration among the relevant stakeholders to combine the structural requirements from architects and engineers with the ecological characteristics proposed by biologists or botanists, indicating the necessity of multidisciplinary knowledge and expertise in green roof design, structure, installation, and maintenance. Therefore, an efficient tool and method are required for sharing and exchange of green roof knowledge

CHAPTER VII

GAMING AND SIMULATION

7.1. 3D green roof board game (The first workshop)

7.1.1. Green roof design by player

In the first game version, the most chosen green roof component was trees while the players in the second game version decided to use many herbs on their green roofs (Figure 7.1). However, bare spaces that occur on the green roofs in both versions were similar and the players intended to imitate the real green roofs that there usually were spaces for walking or doing recreational activities on the green roofs. During the green roof construction step (Figure 7.2), the players exchanged and shared their design concept and knowledge. For instance, the players who had knowledge about plants suggested that the locations of small shrubs and herbs should not be near big trees due to the lack of sunlight. Some players, who were concerned about the aesthetic value and landscape architecture, created symmetrical green roof designs. Moreover, some players shared their suggestions that a larger number of plant species for the environmental benefits, such as air pollution absorption, should be added to the game. While some players needed some extra time for green roof construction.

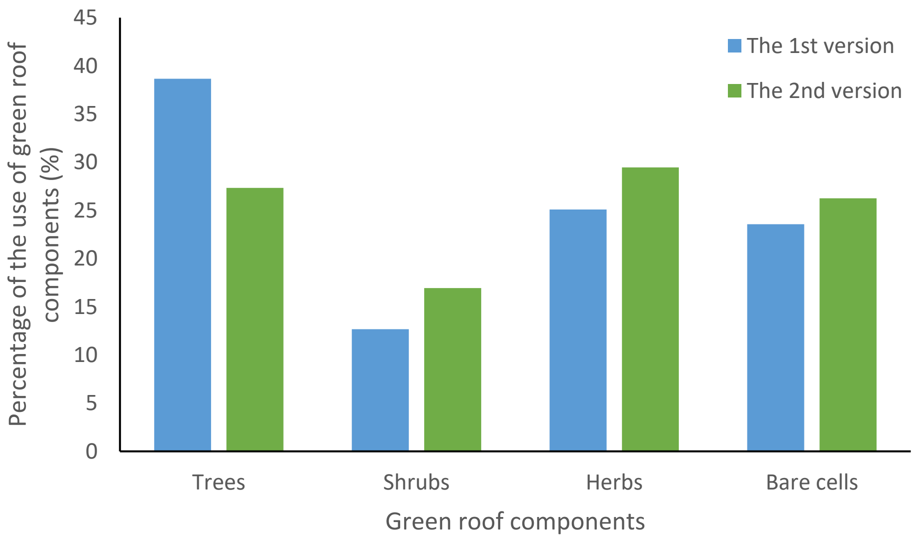


Figure 7.1 Percentage of the use of green roof components during the first and second gaming workshops

(a)

(b)

(c)

Figure 7.2 Atmosphere during the green roof construction step: (a) Green roof construction, (b) a constructed green roof, and (c) discussion of the players about the green roof design

7.1.2. Green roof knowledge of the players before and after playing the 3D green roof board game

In the first game version, the average scores of the pretest and posttest were 8.13 ± 2.85 and 8.50 ± 2.92, respectively, which differed significantly ($p<0.05$) (Table 7.1). The players could answer questions about ecosystem services on green roofs more correctly after they played the game and participated in the discussion. The results also showed that the highest percentage of the correct answers in the posttest were the questions about the benefits of green roofs (question numbers 3, 7, and 10). Nevertheless, the questions about the green roof definition and the role of green roofs for providing the habitat for resident birds (questions number 1 and 5, respectively) gained the lower percentage of the correct answers after the game.

In the second game version, the average scores of the pretest and posttest were 7.23 ± 1.36 and 8.70 ± 1.26, respectively and the posttest average score was significantly higher than that of the pretest ($p<0.05$) (Table 7.1). The percentages of the correct answers of all questions in the posttest were equal to or greater than the pretest. Furthermore, the average score of the pretest and posttest in the second game version was slightly higher than the first game version, but there was no significant difference between these two game versions.

Table 7.1 Percentage of the correct answer in each question in the first and second versions of the game and the average scores of pretest and posttest of both game versions

Question No.	1st game version		2nd game version	
	Pretest	Posttest	Pretest	Posttest
1. Green roofs are only rooftop with installation of growing media and plants.	85.7	72.8	85.0	85.0
2. Ratio of green space area per person in Thailand is similar to the international standard.	70.7	90.5	62.2	96.1
3. Green roofs can provide 4 benefits including global warming mitigation, scenery provision, habitat provision, and product provision.	89.1	98.0	4.7	54.3
4. Green roofs can help to decrease building temperature and air pollution.	88.4	95.2	89.0	89.8
5. Green roofs can play the role as habitat for some resident birds.	59.9	44.2	88.2	89.0
6. Scenery on green roofs can be used to attract tourism and to be learning center.	91.2	93.9	87.4	87.4
7. Diversity of plants on green roofs can help to provides habitat for several animals.	87.8	98.0	88.2	95.3
8. Green roofs can increase wastewater of the building.	80.3	87.8	73.2	89.8
9. Green roofs are suitable for growing small flowers.	66.0	72.8	55.1	84.3
10. Green roofs are the alternative way for increasing green space in urban area.	93.9	98.0	89.0	99.2
Average scores	8.13 ± 2.85	8.50 ± 2.92*	7.23 ± 1.36	8.70 ± 1.26*

Note: * p-value<0.05, n (1st game version) = 147 and n (2nd game version) = 138

7.1.3. Satisfaction of gaming session

The average scores for the ability of board game for collective learning assessed by the players are shown in Table 7.2. In both first and second game versions, all criteria were evaluated as excellent levels. The satisfaction of game equipment and process was assessed by the players and the results are presented in Table 7.3. In the first game version, the results showed that the size of board game and the given time for debriefing, conclusion, and overall of game session were suitable; however, some players needed more plant species and plant tokens and more time for constructing their own green roofs. Therefore, these results led to the second game version that was adapted from the first version by adding more plant species and plant tokens, but the given time for green roof construction could not be extended due to the activity schedule of the Chulalongkorn University Academic Expo. Then, according to the results of the satisfaction assessment in the second game version (Table 7.3), all game equipment and process were suitable, except for the limited time for green roof construction.

Table 7.2 Average scores from the satisfaction assessment for the ability of board game for collective learning

Criterion: Ability of board game for collective learning	1st game version		2nd game version	
1. Playing the game helps me to understand more about green roof benefits.	4.47	±0.54	4.47	±0.53
2. The game is easy to play and is not complex.	4.41	±0.63	4.34	±0.73
3. Playing the game makes me want to increase green space at my residence.	4.13	±0.79	4.36	±0.74
4. I want to transfer the knowledge from this game to other people if I have a chance.	4.14	±0.76	4.28	±0.70
5. Game atmosphere is fun and is not stress	4.53	±0.61	4.6	±0.57
6. Staff are friendly.	4.72	±0.46	4.78	±0.43

Table 7.3 Percentage of the satisfaction in the game equipment and process

Question No.	1st game version		2nd game version	
	Satisfied (%)	Unsatisfied (%)	Satisfied (%)	Unsatisfied (%)
1. Size of board game	93.2	6.8	92.7	7.3
2. Number of plant species for tokens	84.5	15.6	92.0	8.0
3. Number of plant tokens	91.2	8.8	89.1	11.0
4. The given time for creating own green roof	83.8	16.2	79.6	20.4
5. The given time for debriefing and conclusion	96.6	3.4	96.4	3.7
6. The given time for overall of game session	95.3	4.8	96.4	3.6

7.2. 2D green roof board game (The second workshop)

7.2.1. The first gaming session

7.2.1.1. Green roofs designed by players

In the first scenario, the university students aimed to construct the green roofs for recreational spaces, increasing green spaces in urban area, and providing ecological benefits. Therefore, the appearance and beauty of the green roofs were initially considered by the participants. The green roofs were also designed to include the important facilities that provide the desirable utilization and convenience. Some of them designed the green roofs based on landscape design concepts, such as shade, direction, dividing between recreational and garden areas. Moreover, some players focused on the renewable energy, then they installed solar cells on their green roofs. In addition, ecological knowledge, such as using woody trees for carbon storage, was used in the design to solve environmental problems in urban ecosystems. The examples of provided green roof cards and constructed green roofs are presented in Figure 7.3. (Fifteen green roofs created by the university students are presented in Appendix L: Table 1L.)

(a)

(b)

(c)

Figure 7.3 Atmosphere during the green roof construction step: (a) and (b) Example of constructed green roofs by the university students in the first scenario, and (c) discussion of the players about the green roof design

In terms of the use of green roof cards, the selections of green roof cards in each university student group are presented in Figure 7.4. Most of the groups selected five types of the green roof cards. However, some groups used a lot of supporting service cards but only a few cards of provisioning services. One group did not use any provisioning service card. In total, the three green roof cards popularly chosen were the supporting, regulating, and cultural service cards (Figure 7.5).

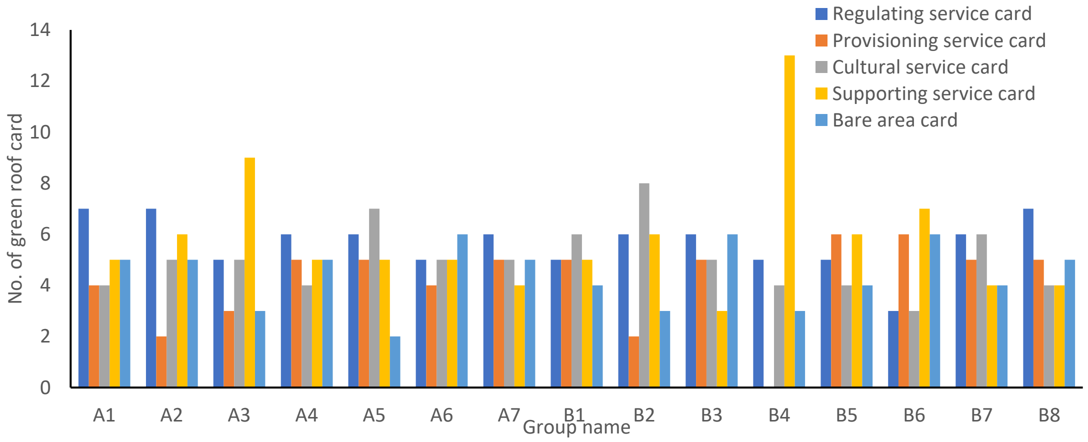


Figure 7.4 Numbers of green roof cards in the first scenario selected by each group

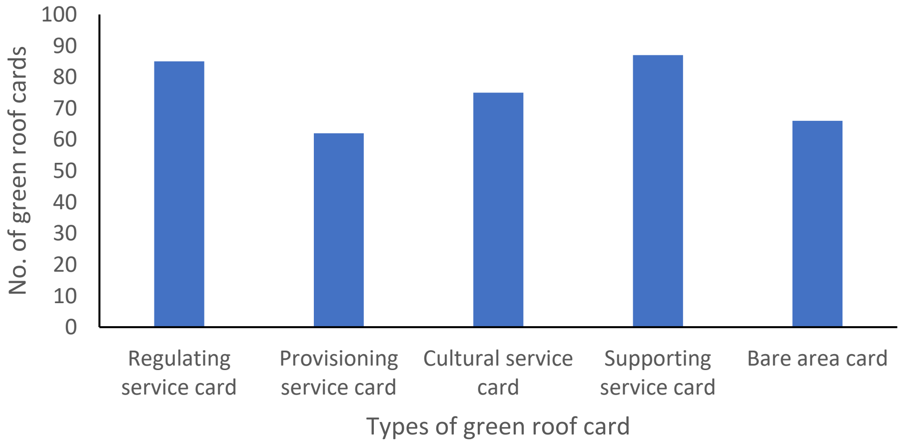


Figure 7.5 Total numbers of green roof cards in the first scenario selected by the players

The initial objective of the second scenario was different from the first scenario. In this scenario, the students were asked to design a green roof to increase ecosystem services. Then, the university students wanted to enhance their diversity and complexity of their green roof ecosystems and tried to provide all four categories of ecosystem services. Therefore, ecological knowledge was used for design and woody plants were selected. Some of them required that the green roof was enhanced with the green area or permeable area to accommodate the woody plants. Hence, the green roof cards showing permeable area were used more than the recreational cards. The examples of constructed green roofs are presented in Figure 7.6. (Fifteen green roofs created by the university students are presented in Appendix L: Table 2L.)

Figure 7.6 Examples of constructed green roofs by the university students in the second scenario

The regulating service cards were highly used by the university students whereas the use of bare area cards was considerably decreased in comparison with the first scenario (Figures 7.7 and 7.8). In addition, the use of provisioning service cards was highly increased. In the second scenario, ecosystem service values on their green roofs were roughly assessed using the rapid assessment checklist. The results showed that total ecosystem service scores of the green roofs ranged from 61 to 98 and the average of total scores was 83. Cultural and regulating services had the higher ecosystem service scores than provisioning and supporting services (73), which were 95 and 88. The average scores of provisioning services greatly varied among 15 groups, which ranged from 33 to 100.

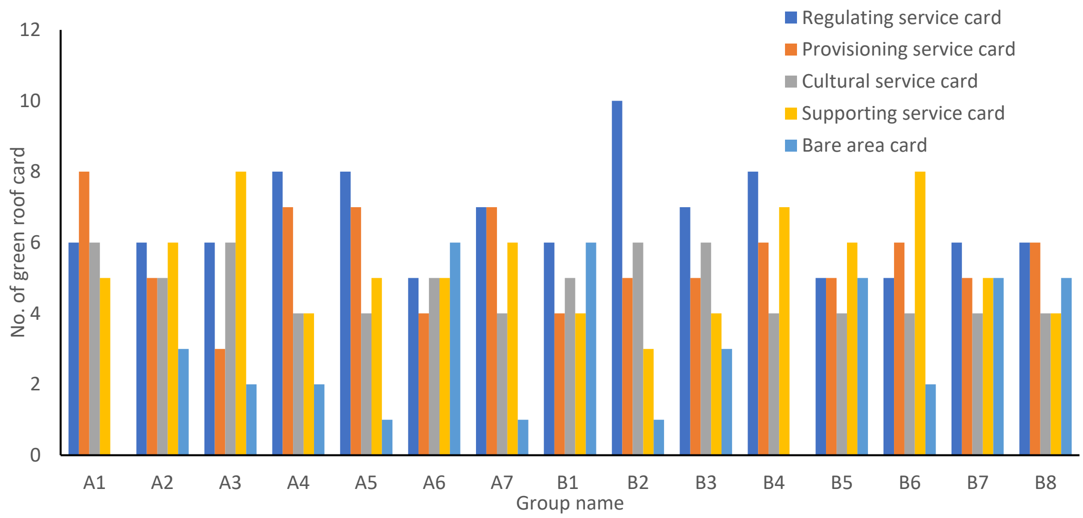


Figure 7.7 Numbers of green roof cards in the second scenario selected by each group

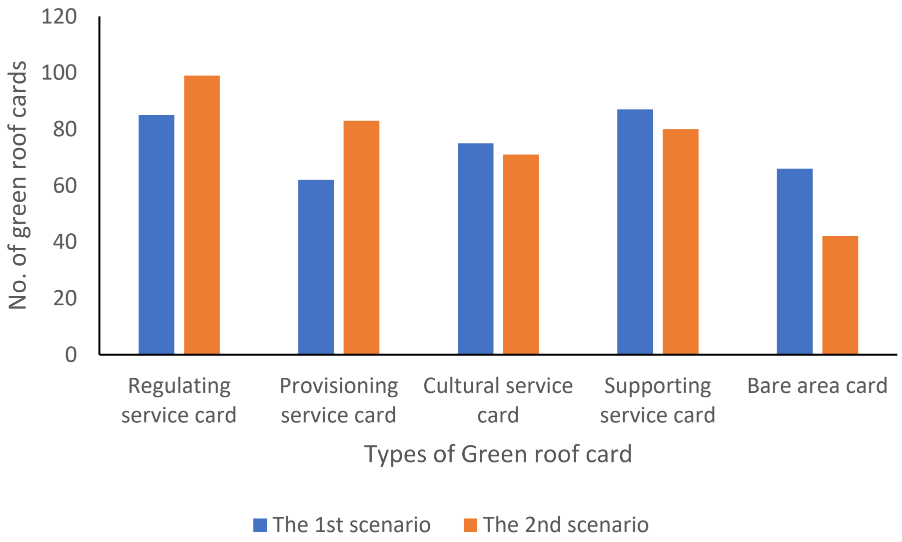


Figure 7.8 A Comparison of total numbers of green roof cards selected in the first and second scenarios

7.2.1.2. Green roof knowledge of the players before and after playing the 2D green roof board game

The results in the first gaming session showed that the average score of posttest (14.01 ± 0.94) was significantly higher than the pretest (12.81 ± 1.45) ($p < 0.05$) (Table 7.4). Therefore, the green roof bingo game could help the university students to know more about green roof and their ecosystem services as well as green roof design based on ecosystem services. According to the answers from the pretest and posttest, the most improved knowledge was about the capacity of green roofs to support plant diversity (question number 11). Interestingly, all university students could answer the question number 6, which was about the benefits of green roofs for decreasing atmospheric carbon dioxide and building temperatures, correctly in both pretest and posttest.

In addition to individual learning, co-learning and knowledge sharing were also observed in both gaming sessions. In terms of green roof design, the preferable green roof characteristics could be learnt through bingo conditions. For example, the players tried to create permeable area and reduce concrete area. During the debriefing session, the players could share their green roof design ideas, such as using a gravel area to enhance soil fauna and creating a beehive to increase the rate of crop pollination. Furthermore, the strategies to encourage green roof implementation in Thailand were also discussed. The university students proposed that the application of green roofs on new buildings should be included in the policy, regulation, or law for increasing green spaces in urban area.

Table 7.4 Percentage of the correct answer in each question and the average scores of pretest and posttest of the first 2D gaming session

Questions	Percentage of the correct answer (%)	
	Pretest	Posttest
1. A green roof is a rooftop with a green color.	97	99
2. A green roof is a rooftop designed in order to save building energy and reduce environmental.	86	89
3. problems. It can be classified as green architecture, clean architecture, or clean technology)	90	91
4. A green roof is growing vegetation on a rooftop or using plants with flowerpots to decorate on a rooftop or balcony.	96	93
5. Green roof technology cannot be found in Thailand.	100	99
6. Green roof technology is one of the strategies for increasing green space in urban areas.	100	100
7. A green roof can help reduce carbon dioxide in the atmosphere and also decrease building temperature.	89	99
8. A green roof can help conserve several plant and fauna species in the urban areas.	81	97
9. A green roof can be used as a food source or agricultural area in the urban ecosystem.	98	100
10. A green roof provides aesthetic values and can be used as a recreational area.	97	99
People can use a green roof as an educational area.	33	68
11. Due to the limitations of green roof structure, the vegetation cannot be planted diversely, then the diversity of vegetation on a green roof are usually low.	84	96
12. A green roof should not be opened for the public because of safety concerns.	90	99

Questions	Percentage of the correct answer (%)	
	Pretest	Posttest
13. Plants that provided environmental benefits (e.g. high potential in carbon storage or air pollution control) should be selected and used on a green roof.	82	99
14. Crops (e.g. vegetables or fruits) can be grown on a green roof.	57	72
15. Plants that grown in flowerpots provided higher environmental benefits than plants that grown directly on a continuous substrate.	97	99
Average scores	12.81 ± 1.45	14.01 ± 0.94*

Note: * p-value<0.05

7.2.1.3. Satisfaction of gaming sessions

The average scores for satisfaction of gaming session are presented in Table 7.5. In the first gaming session, all features and process of the game and outcomes from playing the game were well received by the players. The players also gave some suggestions for a game improvement. Some players indicated that the game could be more complex to make the players used more consideration and knowledge, such as creating the various conditions of weather on green roofs. Moreover, the players needed more cooperation or competition among different groups, such as seizing resources from other groups. However, several players thought overall gaming session took a lot of time, then the criterion about time spent for gaming session received the lowest score in the satisfaction assessment. The players also recommend that this game could be created in a mobile application or a website to reduce some procedures and time.

Table 7.5 Average scores from the satisfaction assessment for the ability of 2D board game for collective learning in the first gaming session

Criteria	Average scores	
1. The green roof game is interesting.	4.35	±0.78
2. The game is easy to play and is not complex.	4.36	±0.79
3. The materials and tools of the game are suitable.	4.36	±0.76
4. The time used for playing the game is suitable.	4.07	±0.96
5. You gained more knowledge about a green roof.	4.65	±0.59
6. You have learnt more about benefits provided by a green roof.	4.63	±0.60
7. You have learnt about designing a green roof in an ecology aspect.	4.50	±0.62
8. The game atmosphere is fun and is not stress.	4.48	±0.70
9. Staffs are friendly.	4.43	±0.75
10. This game can be used as a tool for transferring the knowledge about a green roof to the public.	4.41	±0.74
11. Playing game raises your awareness of the importance of green roof design in an ecology aspect.	4.41	±0.70
12. You think ecology knowledge should be included in designing a green roof.	4.54	±0.62

7.2.2. The second gaming session

7.2.2.1. Green roofs designed by players

The experts and other players in the second gaming session decided to construct green roofs for recreational benefits, saving building energy, water retention, and urban rooftop farming as well as preserving diversity of plants. Thus, most of the concepts and knowledge that the players used for green roof design were from the architecture and environmental expertise. The players planned to grow both native and exotic plants that were difficult to find in order to attract the green roof visitors and enhance the value of green roofs. The examples of constructed green roofs are presented in Figure 7.9. (Five green roofs created by the experts and other players are presented in Appendix L: Table 3L.)

(a)

(b)

(c)

Figure 7.9 Atmosphere during the green roof construction step: (a) and (b) Example of constructed green roofs by the experts and other players in the first scenario, and (c) atmosphere during playing game

During the second gaming session, most of the players also used the green roof cards covering five types of the green roof cards (Figure 7.10). The player who was the engineer chose the highest number of regulating service cards while the architect used the highest number of provisioning service and bare area cards. Figure 7.11 showed that regulating and provisioning services were popularly used by the players.

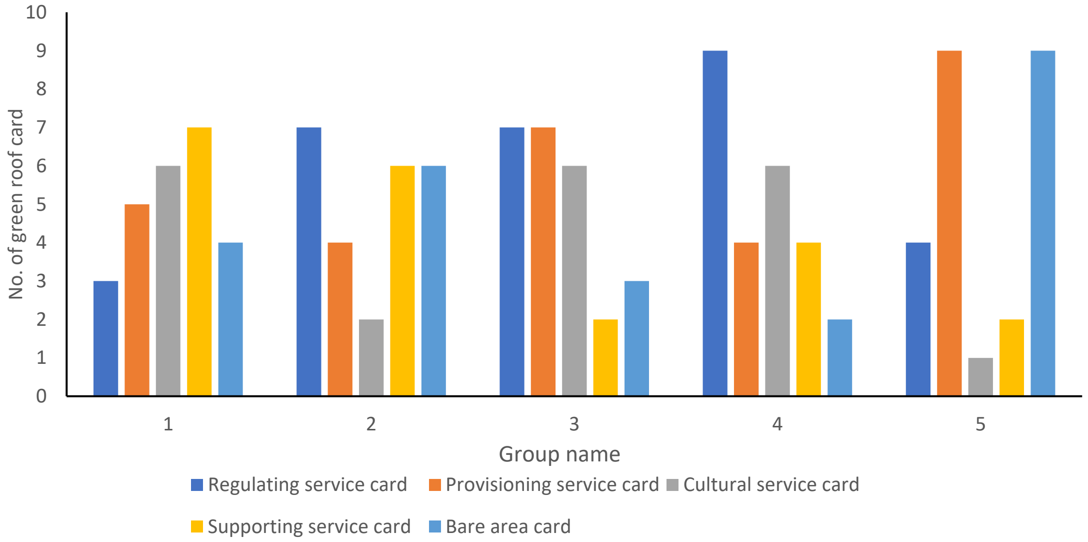


Figure 7.10 Numbers of green roof cards in the first scenario selected by each group

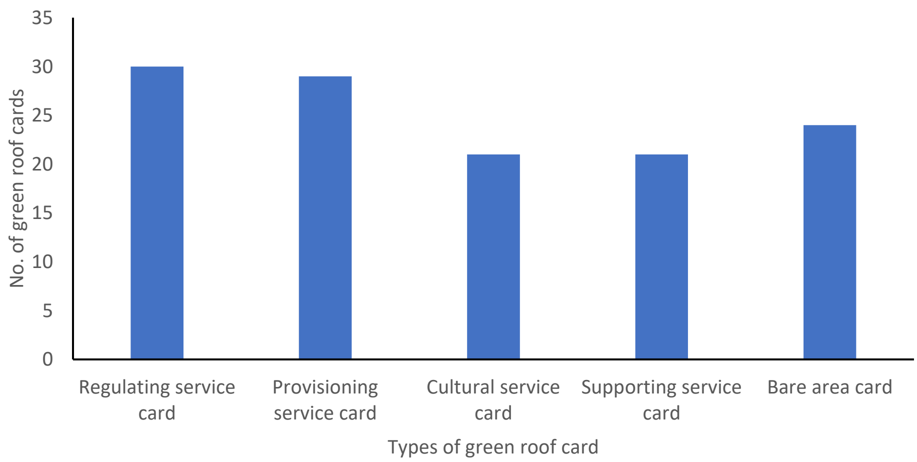


Figure 7.11 Total numbers of the green roof cards in the first scenario selected by the players

In the second scenario, the players decided to enhance provisioning services by growing edible plants. Some players needed to enhance the potential in reduction of building temperature; therefore, they tried using the green area instead of the concrete area and enhancing tree shade. Then, services obtained from green roof and costs of construction had to be carefully considered. The examples of constructed green roofs are presented in Figure 7.12. (Five green roofs created by the experts and other players are presented in Appendix L: Table 4L.)

Figure 7.12 Example of constructed green roofs by the experts and other players in the second scenario

In the second scenario, the green roof cards were selected by each player differently (Figure 7.13). The provisioning service cards were used more while cultural service cards were used considerably less in comparison with the first scenario (Figure 7.14). Considering the ecosystem service scores roughly assessed using the rapid assessment checklist, the findings revealed that total ecosystem service scores of the green roofs ranged from 80 to 98 and the average of total scores was 89. Cultural services gained the highest average score (100) and followed by regulating and habitat services (91 and 90, respectively). The average scores of provisioning services had the lowest average score (73) and ranged from 33 to 100 among the five groups playing the game.

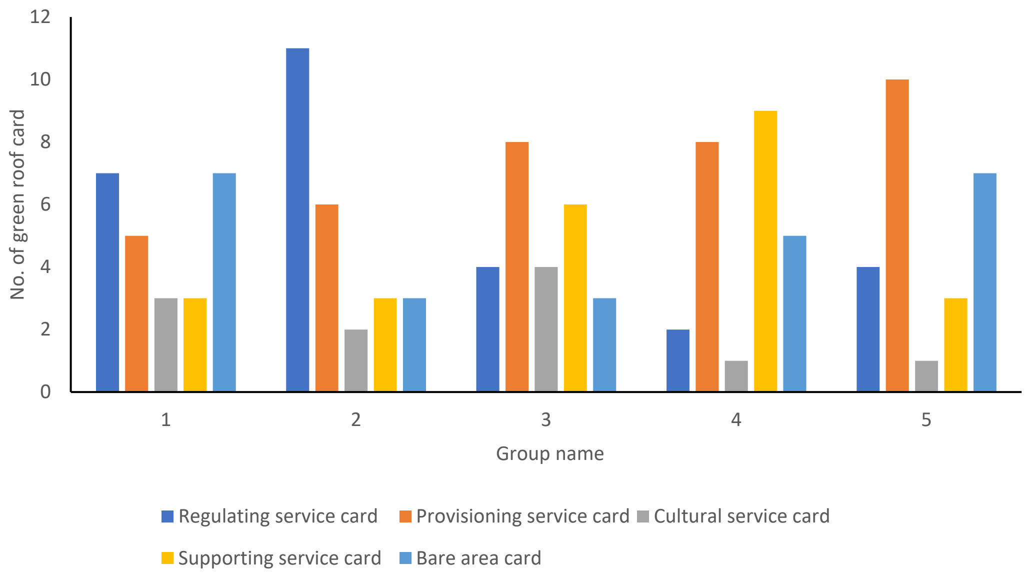


Figure 7.13 Numbers of green roof cards in the second scenario selected by each group

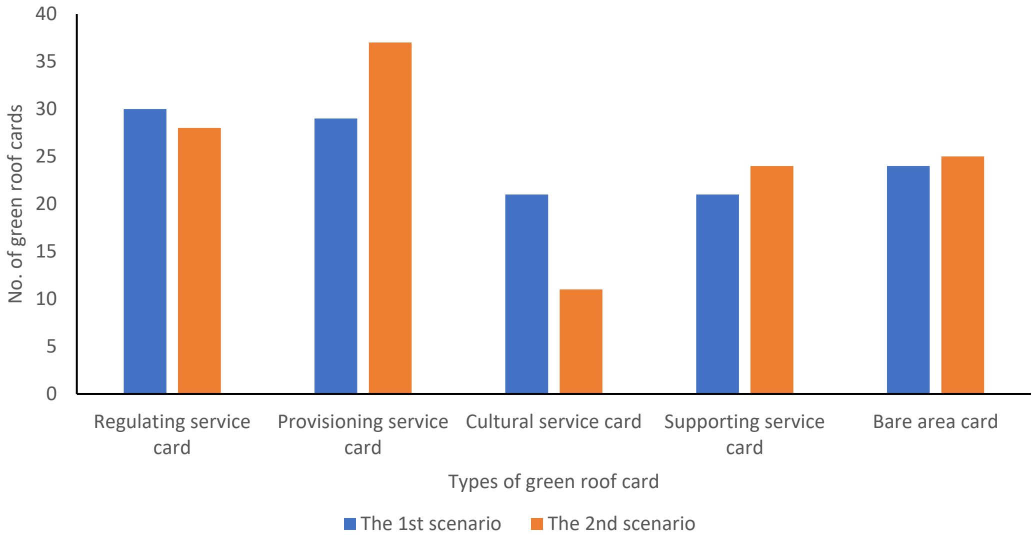


Figure 7.14 A Comparison of total numbers of green roof cards selected in the first and second scenarios

7.2.2.2. Green roof knowledge of the players before and after playing the 2D green roof board game

In the experts and other players session, the results revealed that the average score of pretest (13.80 ± 0.84) was not significantly different from the posttest (14.80 ± 0.45) ($p > 0.05$) (Table 50). Most of the players had the knowledge about green roof before participating the gaming session and were able to answer most questions correctly in both pretest and posttest. Only in questions 10, 11 and 13, which were about the benefits of green roofs and selection of plants for ecology and environment aspects that the increase in correct answers were observed (Table 7.6). Therefore, the green roof bingo game could facilitate the experts and players who had the experiences and knowledge about green roof to have better understanding in some issues.

The experts suggested that green roofs could be promoted through conducting ecotourism and sharing the profits of green roofs in environmental and probably economic aspects to the public. In terms of knowledge used for green roof design, the expert shared his experience that the design process was still lack of the collaboration between different fields of specialists. Then, the ecologist could provide the suggestion list for plants that had the suitable characteristics for growing on green roofs, such as limited loading and ability to absorb air pollution.

Table 7.6 Percentage of the correct answer in each question and the average scores of pretest and posttest of the second 2D gaming session

Questions	Percentage of the correct answer (%)	
	Pretest	Posttest
1. A green roof is a rooftop with a green color.	100	100
2. A green roof is a rooftop designed in order to save building energy and reduce environmental 3. problems. It can be classified as green architecture, clean architecture, or clean technology)	100	100
4. A green roof is growing vegetation on a rooftop or using plants with flowerpots to decorate on a rooftop or balcony.	100	100
5. Green roof technology cannot be found in Thailand.	100	100
6. Green roof technology is one of the strategies for increasing green space in urban areas.	100	100
7. A green roof can help reduce carbon dioxide in the atmosphere and also decrease building temperature.	100	100
8. A green roof can help conserve several plant and fauna species in the urban areas.	100	100
9. A green roof can be used as a food source or agricultural area in the urban ecosystem.	100	100
10. A green roof provides aesthetic values and can be used as a recreational area.	100	100
People can use a green roof as an educational area.	60	100
11. Due to the limitations of green roof structure, the vegetation cannot be planted diversely, then the diversity of vegetation on a green roof are usually low.	80	100
12. A green roof should not be opened for the public because of safety concerns.	100	100
13. Plants that provided environmental benefits (e.g. high potential in carbon storage or air pollution control) should be selected and used on a green roof.	40	80
14. Crops (e.g. vegetables or fruits) can be grown on a green roof.	100	100

Questions	Percentage of the correct answer (%)	
	Pretest	Posttest
15. Plants that grown in flowerpots provided higher environmental benefits than plants that grown directly on a continuous substrate.	100	100
Average scores	13.80 ± 0.84	14.80 ± 0.45

7.2.2.3. Satisfaction of gaming session

In the second gaming session, most of the average scores in the satisfaction assessment were in the good level except interestedness of the game, suitability of the game materials, and atmosphere of the gaming session (the criteria number 1, 3, and 8, respectively) that were evaluated in average level (Table 7.7). The experts who was the architect suggested that the compact elements of green roof cards should be divided into layers, which the players could selected each element separately. Furthermore, the information and benefits of plants, such as the potential in air pollution absorption, carbon storage, and pictures of plants, should be informed in the green roof cards. 3D models might make the game more interesting and they could be created using a 3D printer.

Table 7.7 Average scores from the satisfaction assessment for the ability of 2D board game for collective learning in the second gaming session

Criteria	Average scores	
1. The green roof game is interesting.	3.8	±0.84
2. The game is easy to play and is not complex.	4.0	±0.71
3. The materials and tools of the game are suitable.	3.6	±0.55
4. The time used for playing the game is suitable.	4.0	±0.71
5. You gained more knowledge about a green roof.	4.4	±0.89
6. You have learnt more about benefits provided by a green roof.	4.4	±0.89
7. You have learnt about designing a green roof in an ecology aspect.	4.0	±1.00
8. The game atmosphere is fun and is not stress.	3.8	±0.84
9. Staffs are friendly.	4.4	±0.55
10. This game can be used as a tool for transferring the knowledge about a green roof to the public.	4.6	±0.55
11. Playing game raises your awareness of the importance of green roof design in an ecology aspect.	4.6	±0.55
12. You think ecology knowledge should be included in designing a green roof.	4.6	±0.55

7.3. Comparison between roles of 3D and 2D green roof board games for collective learning

Both 3D and 2D green roof games originally focused on design of the constructed green roofs and the selection of green roof elements (3D-tokens and green roof cards) by the players. However, the players were also concerned about the roof orientation toward the sun and shading by surrounding buildings. Therefore, in addition to types and numbers of the green roof elements, the position of each green roof element was also considered. This results showed that the players could play the assigned role during the game sessions, although both 3D and 2D games had the simple game design. Furthermore, it could be inferred from the results that the players agreed with the ability of the green roof games to represent the reality which is one of the necessary attributes in model creation (Barreteau, Bousquet, and Attonaty, 2001).

The 3D green roof board games were constructed to attract students to participate in the gaming session. The players could create their own green roofs using the provided materials in both game versions. The atmosphere during the workshop was enjoyable and the interaction between the players in the same and different groups was observed. The two 3D game versions could help the players to share their opinion on green roof construction. However, due to the limited choices of shrub and herb elements in the first game version, the players decided to use trees, while shrubs, herbs, and bare cells were highly used in the second game version. Therefore, this findings demonstrated the likely effects of the variety of the green roof elements on vegetation selection and green roof design in the games. Although there was slightly difference between the green roof element variety in the first and second game versions, both game versions were still be able to show the players how significant is green roof design to ecosystem service provision.

The first workshop of the 3D green roof board games could help the players exchange and improve their knowledge, particularly during the debriefing. According to the pretest and posttest scores, there were some issues that the players still provided the wrong answers after playing the game. The first issue was about the green roof definition; however, this probably resulted from the game moderators that did not emphasize the other examples of green roofs (e.g. solar panels), apart from vegetated roofs. While another issue was about the role of green roofs for providing habitats for resident birds and this occurred from the vague question used in the test. Then, the emergence of these two problems during the first game version lead to creation of the second game version. The second game version was composed of higher variety of green roof elements according to the players’ suggestion and the game moderators highlighted more about the definition of green roofs and the benefit for resident birds. In addition, the pretest and posttest were carefully revised in some issues to make sure that the players are on the same page about the questions. Hence, the results showed that the players could answer the questions more correctly. This could confirm the capability of the 3D board game for collective learning.

The players in both gaming sessions of the 2D green roof board game understood the game procedures and rules. However, the green roof design step in the second session (the experts and other players) was more serious than the first session (the university students). In the first gaming session, group members discussed and made a decision together for the green roof design. The game boards and the green roof cards could be used to construct the green roofs. The game was conducted with enjoyable atmosphere. Moreover, competition among groups during the bingo part was observed. The players actively participated in presenting their green roof design. Therefore, they also had the opportunity for sharing and exchanging their green roof design, ideas, and opinions on green roof ecosystem services and utilization with other groups. In the second gaming session, exchanging green roof knowledge among the players was occurred through a debriefing step. In addition, they also had discussions about the effectiveness of the game for a collective learning and attitudes on green roofs as well as the ways to support green roof construction in practice.

The constructed green roofs could demonstrate the perception of the players on green roof ecosystem services. In the first scenario of the gaming session, the regulating and supporting service cards were highly used. These results were consistent with the reality that green roofs have been known for providing regulating services (e.g. reduction of building temperature and mitigation of air pollution) and supporting services (e.g. habitat conservation) (Berardi et al., 2014; Williams, Lundholm, and Scott MacIvor, 2014). Moreover, the use of cultural service cards was high, then it could be inferred that the players also emphasized the cultural services of green roofs (e.g. provision of recreational spaces and aesthetic values). The green roofs constructed by the experts and other players in the second gaming session also apparently reflected the different perception of each player on green roof ecosystem services. The engineer mainly selected the regulating service cards for her green roof design, while the provisioning service and bare cards were mostly found on the architect’s green roof, illustrating the difference in their priority of ecosystem services. In the first scenario, the numbers of bingo criteria that the players could achieved were used to indirectly inform the players how good is their green roofs to provide ecosystem services, while demonstration of ecosystem service scores in the second scenarios could reflect the potential in green roof ecosystem service provision directly. In addition to transferring of knowledge through the bingo criteria, during the debriefing, ecosystem services on green roofs were discussed among the players and the issues about provisioning services on green roofs, such as producing crops, was raised. According to Crookall and Thorngate (2009), new knowledge can be created through the debriefing. Then, the players considerably used more provisioning service cards in the second scenario. Therefore, the results apparently indicated that the players could assimilate what they learnt from the bingo criteria and the discussion during the debriefing.

The 2D green roof game could help the players to improve their knowledge on general characters and ecosystem services on green roofs, and especially in terms of green roof design for enhancing ecosystem services. Furthermore, the players could share and exchange their knowledge during the debriefing as mention above. However, in the first gaming session, the players were the university students in Faculty of Science who have experiences on environmental issues and were familiar with the ecological field. Therefore, the objectives and concepts used for green roof design and construction in the first scenario were mostly based on ecological theories. Moreover, they also had some background knowledge on green roofs, then, all of them could answer some questions correctly since the pretest. This resulted in the significantly higher average scores of posttest. Due to different roles between the role in the game (the green roof designers) and in their daily life (the university students), then, the game could also enable the players to get out of their actual roles and conceive other perspectives (Dionnet et al., 2008). According to Castella (2009), the players played the game based on their personal experience, especially during the initial stage, owing to their lack of familiarity with the game, then actions and decisions of the players during the game could be influenced by their own prior experience and knowledge. Therefore, the environmental issues were likely to be the first issue that they considered. However, in the second gaming sessions, the findings revealed that the posttest scores were only slightly higher than the pretest scores but without statistical significance. Most of the players could already provide the correct answers at the pretest, probably because of their prior expert knowledge of the experts. Nevertheless, the experts and other players have improved their knowledge in only some issues, including the benefits of green roofs and selection of plants for ecology and environment aspects, through playing this 2D green roof board game. Overall, the gaming sessions could provide the collective learning which was confirmed by the pretest and posttest scores.

The 3D and 2D green roof board games showed some differences in their features (Table 7.8). The 3D green roof board game required higher time and cost for preparing game materials and it was more difficult for portability than the 2D green roof board game. However, the 3D board game was likely to attract more players attention in comparison with the 2D board game. Due to the differences of game design and playing procedures, it was difficult to compare the capability for sharing the knowledge or being a learning tool. Nevertheless, the results from the pretest and posttest indicated that both 3D and 2D board games had the capability for collective learning but the level of performance could be varied depending on the game design. The previous research on educational games reported that the 3D board game, called the organ savior game, could significantly improve the human internal organ knowledge of elementary school students in comparison with the 2D board game (Zheng, Cheng, and Chen, 2018). Therefore, it is also interesting to investigate if characteristic of the game materials (i.e. 3D and 2D game boards) can affect the capability for collective learning in an environmental management aspect because the findings from this further study might provide the informative suggestion for designing the effective learning tool.

Table 7.8 A comparison between game attributes in 3D and 2D green roof board games

Attributes	3D board game	2D board game
Time requirement for preparing game materials	High	Low
Cost for game materials	High	Low
Portability	Difficult	Easy
Attraction	High	Medium - High
Capability for communicating and being a learning tool	Medium - High	Medium - High

7.4. Limitations and suggestions for further study

The green roof board games in this study were created following the iterative and continuous process of ComMod (Bousquet et al., 2005). The assessment of ecosystem services on the green roofs was conducted as a field investigation to obtain the essential information for the construction of the green roof board games (e.g. vegetation that usually found on green roofs in Thailand and ecosystem service values that were assigned in the games). Then, the green roof board games were used in the simulations with the participants. New issues arose in the simulation sessions, becoming the focal points for the next round of simulations. For example, the issue about green roof design based on ecosystem services was explored and then it led to the change of the simple green roof board game into the more complex one which was adopted in the subsequent simulation sessions.

The iterative nature of the gaming sessions allowed the learning of new knowledge. The results of pretest and posttest score in this study showed the improvement of green roof knowledge of the players; moreover, the observation of exchanging and sharing design concept and experiences among the players during debriefing could confirm the capability of the green roof board games for being the learning tool. Therefore, the green roof games in this study could achieved the first objective of ComMod approach (Barreteau et al., 2003). In addition, the green roof games could be used beyond being the learning tool. They could be used in decision-making process about green roof design and management, which follows the second objective of ComMod approach. Cooperative engagement of key stakeholders in collaborative modeling is required to achieve the decision making step (Basco-Carrera et al., 2017). Therefore, co-designing the model with stakeholders is one of the processes that should be conducted in the further study.

In addition to the green roof game that focused on only the preferences for ecosystem services, the game could be adapted by adding some features relating to the stakeholders. For example, adding green roof construction costs and economic values of green roof ecosystem services could be useful to explore their impact on the decision-making process of the players. Furthermore, the cooperation or competition among the different participant groups in green roof construction could be applied as the scenarios of the game for encouraging their relationship and possibly enhancing the enjoyable atmosphere. Some suggestions were proposed by the players. For instance, the players of the 2D green roof board game recommended that the cards of green roof elements should be separated into several layers in order to allow the player created their own green roofs more freely. Moreover, the players also stated that the gaming session took a long time and the activity should be shortened to continue the gaming session more actively. Furthermore, the game materials were also commented about the durability. For example, the green roof cards could be easily damaged by a glue that was used for adhesion between the green roof cards and the game board. A mobile application of the game was also suggested as one of the alternative ways in order to avoid taking a lot of time for the gaming session and damaging the game materials. Nevertheless, some players still preferred tangible game materials (3D and 2D board games) to a virtual game in the mobile application. Some players suggested that 3D-game elements can be created using 3D printing. Thus, both 3D and 2D green roof board games and green roof game application could be developed in the further study, and then, the capability in several attributes, such as time requirement for preparation and game implementation, costs, attraction, and the potential in sharing knowledge, should be investigated in order to find the most suitable and efficient types of game for a collective learning about green roofs.

Furthermore, as green roof stakeholders are more diverse than the players in this study, the conduction of green roof gaming session with other stakeholders, such as building owners and urban policy makers, should be encouraged to exchange ideas and gain more perspectives. In the future, the capability of the game for sharing knowledge to multidisciplinary players could be beneficial. Beyond the knowledge sharing and co-learning, the participation of players who have different background knowledge would allow the exploration of their perceptions on green roofs and ecosystem services. The outcomes of the RPG could lead to facilitate joint learning and enhance the collaboration of different stakeholders (Wesselow and Stoll-Kleemann, 2018). Hence, in terms of green roof management, this game can be played by the stakeholders who related to green roofs in order to share different or similar views on green roof design and ecosystem services and this would provide informativeness for several processes of green roof management, such as a green roof policy development.

CHAPTER VIII

GENERAL DISCUSSION

8.1. Factors influencing ecosystem services on the green roofs

Plant types seemed to be one of the influential factors determining regulating services on the green roofs in this study. On ASH, MHT, MTK, and APR, the considerable amount of total carbon was derived from trees. Trees are woody plants which have a higher potential in carbon storage than other non-woody vegetation forms (Fang, Xue, and Tang, 2007). Furthermore, trees provide the shade that can help to decrease the surface and air temperatures (Richards and Edwards, 2017). Trees also have the better performance for removing pollutants from the atmosphere than shrubs or grass (Jim and Chen, 2008). The results from the rapid assessment also showed that the green roofs with trees planted, such as APR, ASH, MHT, and MTK, were able to provide a high estimate of regulating services. Substrates are another important factor as they provide various regulating services on green roofs, such as water retention, and runoff water purification (Lata et al., 2018).

The use of edible plants was considered as an important component of provisioning services on the green roofs in this study. Nevertheless, only one green roof (SGK) in this study was designated as the rooftop farming and consequently provided the excellent performance for provisioning service (food provision). The edible plants were carefully maintained by providing necessary facilities, such as a dripping irrigation system, for supporting food production. On the other hand, other green roofs were constructed for a recreation purpose with ornamental plants as the majority of green roof vegetation. Although some edible plants were found on a few of the other green roofs, only a few species were present, and the actual consumption of the products was not observed owning to lack of availability and a test for marketable quality. This resulted in the low provisioning service scores from the rapid assessment and the low monetary benefits of edible plants estimated from the direct assessment. Although some green roofs (e.g. MHT and MTK) lacked edible plants, these green roofs could potentially provide some suitable conditions and facilities for supporting agriculture, such as substrate characters, sunlight hours, and water resources. Therefore, it demonstrates the potential of the enhancement of food provisioning on the green roofs if the required elements (e.g. edible plants and suitable substrate) and proper management for rooftop agriculture are observed. In addition to edible plants, the uses of plants for medicinal, ornamental, and other benefits (e.g. fuelwood and timber) can be observed on green roofs (Dirks et al., 2016; Zinia and McShane, 2018). Nevertheless, in this study, these benefits from plants were not truly used, making it difficult to estimate the precise values of provisioning services. In addition, the provisioning potential of green roofs were hardly utilized.

Because most of the green roofs in this study were constructed for recreational purpose, the results showed that the values of their cultural services were high. Recreation facilities (e.g. chairs, sunshade, footpath, and a swimming pool) were found on most of the green roofs and their access was freely allowed. However, the green roofs with limited educational facilities and activities, such as MHT and MTK, provided lower cultural services. Therefore, the existence of recreation facilities and conduction of education activities are probably significant factors that influence the cultural service potential on the green roofs. Core facilities, such as seating and shelter, accessibility and safety were the most desirable attributes of urban green spaces (Zhang et al., 2013). Hence, the more important facilities and attributes provided on the green roofs might attract the greater numbers of green roof visitors and eventually resulted in the higher cultural service performance.

The substrate conditions of the green roofs in this study could sustain the survival of soil fauna, providing supporting services. The diversity of soil arthropods on green roofs was also influenced by the vegetation cover (Schindler et al., 2011). Thus, higher vegetation cover can provide the greater ability to conserve fauna habitats, increasing supporting service potential. Furthermore, the supporting services on the green roofs could be affected by habitat fragmentation that occurred on green roofs with the flowerpot design (i.e. SXV and SGT). This is because smaller patches can support fewer species of fauna in comparison with larger patches (Fahrig, 2003). Therefore, a continuous coverage substrate of green roofs with the garden bed design is preferable to those of the flowerpot design in order to enhance the habitat conservation.

8.2. Provision and priority of green roof ecosystem services

The findings from both direct and rapid assessments indicated that the green roofs in this study could provide four main categories of ecosystem services. The rapid assessment showed that provisioning and cultural services were the limiting ecosystem services of all of the selected green roofs. The green roofs provided relatively higher regulating and supporting services than provisioning and cultural services. Even though these green roofs were constructed primarily for recreation purposed, the regulating and supporting services are the benefits that are inherent to man-made ecosystems installed on the rooftops. The green roofs in this study were able to support various ecosystem functions, ranging from habitats for urban wildlife to stormwater management. On the other hand, provisioning and cultural services values varied in the different green roofs depending on the characteristics of the green roofs, such as the use of edible plants, the access and facilities for recreation, and the opportunity to conduct educational activities.

The rapid assessment allowed a comparison among the four categories of ecosystem services estimated on the green roofs, showing the potential to provide ecosystem services. The green roofs were able to provide the highest level of regulating services, followed by supporting, cultural, and provisioning services, respectively

(Table 8.1). The ecosystem service values estimated by the direct assessment could not be explicitly compared between different service types due to different units of the values.

The perceptions of the public and the participants of the gaming and simulation represented the expected demand of ecosystem services from green roofs (Table 8.1). Both focus groups, namely (i) the students and workers and (ii) the experts, gave the highest priority to regulating services but ranked the other categories of ecosystem services differently. During the gaming sessions, however, the university students considered supporting services as a higher priority than other ecosystem service categories. This might result from their prior knowledge of ecosystem services, especially biodiversity conservation. Thus, the function of green roofs as habitat provision for organism has received more attention than other functions. On the contrary, the experts ranked supporting services as the lowest priority. Due to the value of green roofs in a commercial aspect, the green roofs possibly were dictated to serve recreation and social amenity and human activities could restrict animals from inhabiting the green roofs. Moreover, the predominance of hardscapes on green roofs might not suitably support habitat provision as well as wildlife preservation (Wong et al., 2005). In this study, the experts playing the game were likely to emphasize regulating services as the most importance, followed by provisioning services. Even though recreation and aesthetics were usually the objectives for the construction of green roofs, cultural services were not be ranked as the first priority. This was probably because the ranking criterion was about the impact on improvement of the urban environment. However, cultural services seemingly have less direct or obvious relation to improvement of the ecosystem service health in comparison with other services (Pedersen Zari, 2012).

In this study, the existing green roofs had the capability to provide relatively more of regulating services, followed by supporting, cultural, and provisioning services, respectively. The ranking of provision was similar to the ranking of importance of ecosystem services as determined by the students and workers, although the actual order differed slightly among the groups of correspondents. The different prioritization of services by different stakeholders could influence the decision in ecosystem protection and the lower perceived value of ecosystem services could also result in an impairment of ecosystem services (Pan, Marshall, and Maltby, 2016). In this study, therefore, some issues about how to manage the green roofs to maintain both satisfaction of people and quality of ecosystem services were raised. For example, there was the curiosity about the suitable strategies that should be used when the differences between provision and priority of ecosystem services occur. Specifically, the discussion was whether the perception of people on the perceived value of each green roof ecosystem service should be adjusted or the capability of green roofs to provide ecosystem services should be improved in order to match the perception. Then, more comprehensive understanding of ecosystem service provision and identification of prioritized services in different stakeholders should be investigated and then they could help to enable the encouragement of green roof construction and also improvement of green roof management, policy, and decision making in terms of ecological aspects.

Apart from that, green roofs are essentially man-made ecosystems. In addition to ecological aspects, the perspective of humans should thus be taken into account. The ecosystem quality can also depend on the objectives of the people setting them (Freyfogle and Newton, 2002). For example, a hotel owner might estimate a green roof by the number of customers attracted by the green roof, a rooftop farming owner by crop yield, and a green roof visitor by availability of facilities for recreation. Therefore, the ability of green roofs to serve the intended functions could roughly determine the quality of the green roofs. Then, some policies can be established in order to create suitable green roofs that satisfy both ecological aspects and human needs, consequently improving the quality of green roof ecosystems and the ability to provide ecosystem services.

Table 8.1 Ecosystem service priority indicated by different approaches

Ecosystem service types	Ecosystem service priority					
	Direct assessment	Rapid assessment*	Investigation of people perception**		Game and simulation**	
			Students and workers	Experts	University students	Experts
Regulating services	N/A	1	1	1	2	1
Provisioning services	N/A	4	4	3	4	2
Cultural services	N/A	3	3	2	3	3
Supporting services	N/A	2	2	4	1	3

Note: *Approach indicated the ranking of green roof ecosystem service provision
**Approaches indicated the ranking of green roof ecosystem service demand
N/A means the ranking is not applicable

8.3. Process for investigation of ecosystem services on green roofs

The process for investigating green roof ecosystem services in this study is composed of three approaches, including ecosystem service assessment, investigation of people perception on green roof ecosystem services, and conduction of green roof games. The direct assessments of each green roof ecosystem service were studied. The ecosystem service values were presented in conventional unit scales of each service, such as kg of carbon storage, market prices of products, and diversity index of fauna. Due to the different units of each service value estimated by the direct assessment, it is difficult to determine the total ecosystem service values and also the comparable ecosystem service values. Although de Groot et al. (2012) proposed the approach to transfer many multi-dimensional variables of ecosystem services into monetary units and consequently the ability to aggregate and compare ecosystem service values, the monetary valuation is probably not a fruitful approach due to some limitations, such as unrealistic and uncertainty outcome (Baveye et al., 2013).

The rapid assessment is an innovative time-saving tool to evaluate green roof ecosystem services and gave outputs as normalized scores that could be compared between different service types and between different green roof sites. Moreover, the participation of stakeholders in the assessment can be encouraged owning to the time-saving and easy process. However, if more intensive outputs are required, a more refine assessment should be conducted.

The investigation of people perception helps to determine the important issues about green roofs and knowledge that should be considered and improved. Then, the green roof games were created using the results from the first two approaches. The assessment of green roof ecosystem services provided the information to design the games and the concerned issues from the study on people perception were considered as the goal for implementing the learning tool. Although a lot of time had to be used to conduct all process, this framework can provide the necessary data that is informative for the further research on green roof in Thailand, such as the rapid assessment tool for green roof ecosystem services and the emphasized green roof ecosystem services in people's view.

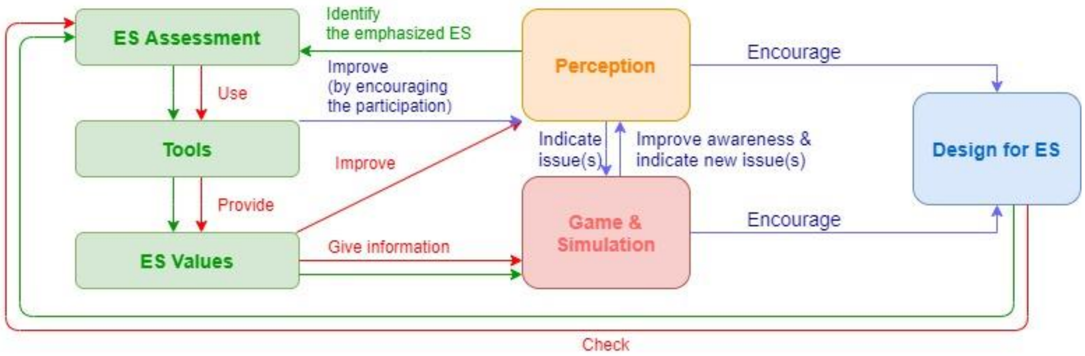
Nevertheless, this process framework can be adapted depending on the requirement and some limitations, such as time for conducting the process. For example, the investigation of perception and ecosystem service priority can be conducted as the first step to identify the emphasized services. Then, only those services can be selected for the assessment. After that, either the direct measurements or the rapid assessment could be sufficient because the perceptions on only the selected ecosystem services are focused on, thus saving time and effort in conducting the assessment. However, due to the different weaknesses and strengths of these two assessment approaches, the suitable assessment techniques should be wisely selected depending on the objectives of the assessment, the required level of accuracy for ecosystem service values, and the availability of data, assessor's knowledge, time, and cost. In the rapid assessment process, it is possible for modifying the weight of variables then, instead of equal weighting, the variables can be weight differently depending on the priority of each service. Lastly, the green roof game can be implemented with both general stakeholders and experts together to learn and improve green roof knowledge collectively. Moreover, this framework can be also used to investigate ecosystem services of other urban ecosystems that usually involved with humans in order to find the suitable strategies to maintain the satisfactions in both ecological and societal aspects (e.g. quality of the ecosystems and provision of desirable ecosystem services).

CHAPTER IX
CONCLUSION AND RECOMMENDATIONS

9.1. Conclusion

The green roof ecosystem services of four main categories, including regulating, provisioning, cultural, and supporting services, were evaluated using the direct assessments and the rapid assessment tool developed during this study. The findings suggested that the selected green roofs in Bangkok, Thailand, could provide ecosystem services from all four categories and regulating and supporting services were the more substantial components of ecosystem services supplied by the intensive green roofs in this study. However, the potential in ecosystem service provision of each green roof differed, depending on biophysical characteristics, such as plant types, vegetation cover, substrate, design types, and provision of core facilities. The most important ecosystem services prioritized by university students, workers, and experts were regulating services; however, other priority ranks were slightly different depending on their prior knowledge. The explorations of ecosystem service provision and priority on green roofs could encourage the proper green roof management, policy, and decision making in order to satisfy both ecological aspects and human needs. Apart from that, the direction of green roof application in Thailand tended to be expanded because more people recognized the benefits of green roofs. However, there were also some misunderstandings about the green roof definition and the necessary of green roof construction; moreover, the major possible barrier for green roof construction in Thailand were the high construction and maintenance cost. Then, the 3D and 2D green roof board games were used as the tool for facilitating a collective learning and improving knowledge about green roofs and their ecosystem services. The findings suggested that the knowledge about green roofs could be improved through playing the green roof games; moreover, the design and decision for green roof construction could indirectly reflect the perception of people and possibly, indicate the new interesting topics for further research and workshop. This proposed process of the integrative framework (Figure 9.1) could provide both ecological and societal outputs of the green roofs and their ecosystem services. These outputs could facilitate the management and encouragement of ecosystem-based design of green roofs that could satisfy stakeholder needs and also contribute good ecological quality within the limitations of green roofs.

Furthermore, this framework is also an adaptable approach. The adapted or additional processes are suggested as green arrows in Figure 9.1. The framework can be adapted depending on the requirements or limitations. For example, the investigation of perception can be conducted as the first step in order to save time and effort for carrying out the process. Then, only emphasized services in people perception can be selected for ecosystem service assessment which is the second step. After that, the investigation can be conducted by following the original proposed process that is creation of game and simulation. Therefore, this integrative process has the potential to be useful for the ecosystem service assessment and management of other constructed ecosystems and probably human dominated ecosystems in urban area. It can help to find suitable strategies for maintaining the satisfactions of both ecological and societal aspects.



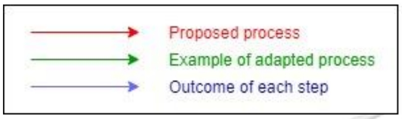


Figure 9.1 The integrative process for investigating ecosystem services and encouraging ecosystem-based design of green roofs

9.2. Recommendations

9.2.1. Recommendations for implementation

Design and management of green roofs should be improved to firstly achieve the regulations and standards for urban green space. The results indicated that the green roofs lacked some characters to achieve the ecological and environmental quality standards. The standards for urban green space suggested that plant species that have medium and high potential for carbon storage should be selected such as *Acacia auriculiformis*, *Cassia fistula*, and *Lagerstroemia speciosa* (Office of Natural Resources and Environmental Policy and Planning, 2014). Moreover, selected vegetation should be diverse and suitable for the area. Therefore, in addition to completing the standards for urban green spaces, the proper plant selection in an environmental aspect also helps to increase the green roof regulating services. A high diversity of plant species and utilization types are suggested for improving provisioning, cultural, and supporting services. In addition, garden bed green roofs with high vegetation cover and continuous coverage substrate are recommended for supporting high fauna diversity and also helping to enhance some regulating services, such as stormwater retention.

Increasing the utilization of green roofs could also be obtained through management. According to the guidelines for ecological beauty on green roofs (Sutton, 2014), green roofs must be seen and experienced by the members of the public, who are allowed to access the green roofs and participate in activities that increase their ecological knowledge, therefore increasing the cultural services of the green roofs. For example, the Hanul Madang rooftop garden at Seoul National University was used as the place for conducting the activities which can help develop people social relation, such as cultivation, garden management activities, and even holding events or party; moreover, it was also used for students to gain direct experience in garden design (Son, 2018). Apart from recreation and education benefits, there were many ideas to increase other cultural benefits. For example, traditional garden concept could be applied for green roof installation in order to preserve the cultural heritage. Furthermore, to enhance cultural service value of green roofs, ecotourism might be conducted by allowing tourists to visit and study the green roofs. Therefore, if green roofs were properly designed and managed, the higher quantity and quality of ecosystem service provision and diverse utilizations of green roofs would be supported.

This study has identified financial concerns and limited knowledge as two main barriers to the installation of more green roofs in Thailand. The stakeholders were seriously concerned about the high construction and maintenance costs of green roofs. Financial support from the government for green roof construction could be one of the incentives to increase green roof installations. For example, a partial repayment of green roof construction cost could be offered if the green roof can achieve the requirements, such as the size of green roof. Furthermore, the lack of green roof knowledge was also identified as the other major obstacle preventing installation of more green roofs in Thailand. Therefore, the public should be educated about the important knowledge regarding green roofs, such as structural engineering, landscape architecture, and even vegetation selection. Organizations involved in the planning and regulation of the environment should also provide a guideline for green roof design, construction, and management. For instance, suitable vegetation used on green roofs can be compiled and created as a suggestion list to encourage a sustainable green roof. Moreover, the government or relevant organizations could indirectly supply the technical knowledge through installation of green roofs on the bare rooftops of government or private offices and allowing people to visit for learning as a green roof case study. This strategy possibly helps to enhance the opportunity of people to have an experience in green roof uses.

9.2.2. Future research

Due to the lack of information and research on green roofs in the tropical region, some reference values used in the rapid assessment were derived from the studies in the temperate region. However, there are several differences between these two regions, such as climate, season, and vegetation; therefore, the investigation of the reference values of each indicator in the rapid assessment of green roof ecosystem services should be examined in order to provide more accurate outputs of ecosystem services of tropical green roofs. Moreover, the practical use and participation of the stakeholders, both specialists and non-specialists, in the rapid ecosystem service assessment should be carried out to confirm the capability of the innovative tool for encouraging the participation of stakeholders in the assessment process. Furthermore, monitoring and evaluation of the framework should be developed and implemented in the further study because it can indicate how each approach used in the process affect the stakeholder perception on green roof application and management and possibly enhance the effectiveness of the process by proper adaptation of the approaches.

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APPENDIX A
INFORMATION OF GREEN ROOF STUDY SITES

1. Aor Por Ror Building (APR)

The green roof (APR) is located on the sixth floor of Aor Por Ror Building, Faculty of Medicine, Chulalongkorn University. APR’s approximate age is14 years old. The green roof is officially opened during 7:00 A.M. – 7:00 P.M. Only university students, professors, and staffs are allowed to access and use the green roof. The vegetation on APR is composed of trees, shrubs, herbs, and grasses.

Figure 1A Green roof on Aor Por Ror Building (APR)

2. Anantara Siam Bangkok Hotel (ASH)

The green roof (ASH) is located on the second floor of Anantara Siam Bangkok Hotel. The age of green roof on ASH is approximately 30 years old. The hotel customers and residents are able to access and use the green roof during 6:00 A.M. – 8:00 P.M. The vegetation on ASH is composed of trees, shrubs, herbs, and grasses.

Figure 2A Green roof on Anantara Siam Bangkok Hotel (ASH)

3. Mahitaladhibesra Building (MHT)

The green roof (MHT) is located on the fifth floor of Mahitaladhibesra Building, Faculty of Commerce and Accountancy, Chulalongkorn University. MHT is officially opened during 6:00 A.M. – 7:00 P.M. Only university students, professors, and staffs are allowed to access and use the green roof. The vegetation on MHT is composed of trees, shrubs, and herbs.

Figure 3A Green roof on Mahitaladhibesra Building (MHT)

4. Mitkorn Mansion (MTK)

The green roof (MTK) is located on the second floor of Mitkorn Mansion. MTK has lasted for 30 years. Only the mansion residents are able to enter and use the green roof. There is a security guard who takes care of the green roof during 6:00 A.M. – 8:00 P.M. The vegetation on MTK is composed of trees, shrubs, and herbs.

Figure 4A Green roof on Mitkorn Mansion (MTK)

5. Siam Green Sky (SGK)

The Siam Green Sky (SGK) was located on the seventh floor of Siam Square One. SGK was a farming rooftop. People were occasionally allowed to enter the green roof when there were educational activities such as workshops about farming, crop cultivation, food production and safety processes, and urban food security. Unfortunately, it was abandoned and closed down in 2017. Therefore, SGK lasted for two years. The vegetation on SGK found during the study period was composed of herbs and grasses.

Figure 5A Siam Green Sky (SGK)

6. SG Tower Building (SGT)

The green roof (SGT) is located on the eleventh floor of SG Tower Building. SGT has lasted for 27 years and has been used for installation of electrical equipment, including antennas and air conditioner units. SGT is a restricted area. People are not allowed to access and use the green roof. The vegetation on SGT is composed of trees, shrubs, and herbs.

Figure 6A Green roof on SG Tower Building (SGT)

7. 60th Anniversary Building at Faculty of Veterinary Science (SXV)

The green roof (SXV) is located on the ninth floor of 60th Anniversary Building, Faculty of Veterinary Science, Chulalongkorn University. SXV is officially opened during 7:00 A.M. – 7:00 P.M. Only university students, professors, and staffs are allowed to access and use the green roof. The vegetation on SXV is composed of trees and shrubs.

Figure 7A Green roof on 60th Anniversary Building at Faculty of Veterinary Science (SXV)

APPENDIX B
COST FOR GREEN ROOF INSTALLATION

Table 1B Cost prices used for calculation of green roof installation

Material		Unit	Material cost THB/Unit	Labor cost THB/Unit
Vegetations				
Acacia auriculaeformis	กระถินณรงค์	tree(s)	490	300
Adonidia merrillii	หมากนวล	tree(s)	1200	300
Aechmea fasciata	สับปะรดสี	pot(s)	150	30
Aerva sanguinolenta	แดงชาลี	pot(s)	15	5
Alocasia macrorrhizos	กระดาด	pot(s)	95	15
Artabotrys siamensis Miq.	การเวก	tree(s)	250	300
Asplenium nidus	เฟิร์นข้าหลวงหลังลาย	pot(s)	70	30
Asystasia gangetica	บุษบาริมทาง ใบด่าง	tree(s)	10	5
Axonopus compressus	หญ้ามาเลเซีย	m^2	100	50
Bambusa sp.	ไผ่	clump(s)	100	30
Bougainvillea spectabilis	เฟื่องฟ้า	pot(s)	180	30
Callisia fragrans	กวนอิมพันมือ	tree(s)	10	5
Caryota urens	เต่าร้าง	tree(s)	180	10
Cerbera odollam	ตีนเป็ดน้ำ	tree(s)	750	300
Cheilocostus speciosus	เอื้องอินโด	pot(s)	65	5
Chlorophytum laxum	เศรษฐีเรือนนอก	pot(s)	10	5
Chrysopogon zizanioides	หญ้าแฝก	m^2	30	
Clitoria ternatea	อัญชัน	pot(s)	50	5
Cocos nucifera	มะพร้าว	tree(s)	2630	300
Codiaeum variegatum	โกสน	pot(s)	7	5
Copernicia prunifera	ปาล์มแว็กซ์	tree(s)	2500	300
Cordyline fruticosa	หมากผู้หมากเมีย หางหงส์	pot(s)	80	30
Cynodon dactylon	หญ้าเบอร์มิวดา	m^2	50	50
Dieffenbachia seguine	ช้างเผือก	tree(s)	80	5
Dracaena loureiri	จันทน์ผา	tree(s)	2500	300
Dracaena surculosa	ไผ่ฟิลิปปินส์	pot(s)	25	5
Duranta erecta	เทียนทอง	pot(s)	15	5
Dypsis lutescens	หมากเหลือง	clump(s)	160	250
Ehretia microphylla	ชาฮกเกี้ยน	pot(s)	6	5
Epipremnum aureum	พลูด่าง	tree(s)	15	3
Euphorbia pulcherrima	คริสมาสต์	pot(s)	75	5
Ficus annulate	ไทรอินโด	tree(s)	240	30
Ficus benjamina	ไทรย้อยใบแหลม	pot(s)	700	300
Ficus microcarpa	ไทรทอง	pot(s)	150	30
Ficus pumila	ตีนตุ๊กแก	tree(s)	300	30

Material		Unit	Material cost THB/Unit	Labor cost THB/Unit
Ficus sp.	ไทรเกาหลี	pot(s)	260	30
Gardenia jasminoides.	พุดศุภโชค	pot(s)	6	5
Graptophyllum pictum	ใบทอง	tree(s)	200	5
Heliconia spp.	ธรรมรักษา	pot(s)	35	5
Hibiscus spp.	ชบา	pot(s)	5	5
Homalomena rubescens	ว่านเสน่ห์จันทร์แดง	tree(s)	45	10
Hymenocallis littoralis	พลับพลึงตีนเป็ด	pot(s)	25	30
Ixora chinensis	เข็มญี่ปุ่น	pot(s)	6	5
Ixora finlaysoniana	เข็มพวงขาว	tree(s)	8	5
Ixora longifolia	เข็มเศรษฐีมาเลเซีย	pot(s)	6	5
Ixora macrothyrsa	เข็มเศรษฐี	pot(s)	6	5
Mangifera indica	มะม่วง	tree(s)	820	300
Ocimum tenuiflorum	กะเพรา	m^2	27	3
Millingtonia hortensis	ปีบ	tree(s)	1600	300
Mimusops elengi	พิกุล	tree(s)	1500	300
Moringa oleifera	มะรุม	tree(s)	545	300
Murraya paniculata	แก้ว	pot(s)	180	30
Nephrolepis cordifolia	เฟิร์นใบมะขาม	pot(s)	15	5
Ocimum × africanum	แมงลัก	m^2	27	3
Ocimum basilicum	โหระพา	m^2	27	3
Pandanus amaryllifolius	เตยหอม	pot(s)	10	5
Pandanus tectorius	การะเกด	pot(s)	11	5
Philodendron xanadu	ซานาดู	tree(s)	45	10
Phymatosorus scolopendria	เฟิร์นหลังสวน	pot(s)	25	30
Pisonia grandis	แสงจันทร์	pot(s)	1045	30
Plumeria rubra	ลั่นทม	tree(s)	1475	300
Polyalthia longifolia	อโศกอินเดีย	tree(s)	130	300
Pseuderanthemum carruthersii	ใบนาก	tree(s)	200	5
Pseuderanthemum crenulatum	เข็มม่วง	tree(s)	100	5
Ptychosperma macarthurii	หมากเขียว	clump(s)	250	250
Ravenala madagascariensis	กล้วยพัด	tree(s)	2500	300
Rhapis excelsa	จั๋ง	clump(s)	150	10
Ruellia squarrosa	ต้อยติ่งฝรั่ง	tree(s)	12	5
Sansevieria spp.	ลิ้นมังกร	pot(s)	25	5
Spathiphyllum spp.	เดหลี	pot(s)	35	5
Sphagneticola trilobata	กระดุมทอง	pot(s)	8	5
Tabebuia aurea	เหลืองปรีดียาธร	tree(s)	2500	300
Tabernaemontana pandacaqui	พุดร้อยมาลัย	pot(s)	6	5
Thrinax parviflora	ปาล์มสะดือเขียว	tree(s)	1500	300
Wodyetia bifurcata	ปาล์มหางกระรอก	tree(s)	800	300
Wrightia religiosa	โมกบ้าน	pot(s)	100	30

Material	Unit	Material cost THB/Unit	Labor cost THB/Unit
Substrate			
Soil	m^3	450	150

Data modified from the (Environment department of The Bangkok Metropolitan Administration, 2013; Energy Regulatory Commission, 2016)

APPENDIX C
MONETARY BENEFITS OF PRODUCTION ON GREEN ROOFS

Table 1C Monetary benefits of edible and ornamental plant species

Plant species		Unit	Monetary benefits	
			Edible plants	Ornamental plants
			THB/kg	THB/Unit *
Acacia auriculaeformis	กระถินณรงค์	tree(s)	-	490
Aechmea fasciata	สับปะรดสี	pot(s)	-	64
Aerva sanguinolenta	แดงชาลี	pot(s)	-	15
Dracaena surculosa	ไผ่ฟิลิปปินส์	pot(s)	-	25
Alocasia macrorrhizos	กระดาด	pot(s)	-	95
Artabotrys siamensis	การเวก	tree(s)	-	250
Asplenium nidus	เฟิร์นข้าหลวงหลังลาย	tree(s)	-	10
Asystasia gangetica	บุษบาริมทาง ใบด่าง	tree(s)	-	10
Axonopus compressus	หญ้ามาเลเซีย	m^2	-	13
Bambusa sp.	ไผ่	clump(s)	-	100
Bougainvillea spectabilis	เฟื่องฟ้า	tree(s)	-	50
Callisia fragrans	กวนอิมพันมือ	tree(s)	-	10
Ehretia microphylla	ชาฮกเกี้ยน	pot(s)	-	6
Caryota urens	เต่าร้าง	tree(s)	-	180
Cerbera odollam	ตีนเป็ดน้ำ	tree(s)	-	750
Chlorophytum laxum	เศรษฐีเรือนนอก	pot(s)	-	10
Dypsis lutescens	หมากเหลือง	tree(s)	-	147
Clitoria ternatea	อัญชัน	pot(s), kg	100	50
Cocos nucifera	มะพร้าว	tree(s), kg	16.73	2630
Codiaeum variegatum	โกสน	tree(s)	-	100
Copernicia prunifera	ปาล์มแว็กซ์	tree(s)	-	147
Cordyline fruticosa	หมากผู้หมากเมีย หางหงส์	pot(s)	-	80
Cheilocostus speciosus	เอื้องอินโด	pot(s)	-	65
Cynodon dactylon	หญ้าเบอร์มิวดา	m^2	-	13
Dieffenbachia seguine	ช้างเผือก	tree(s)	-	80
Dracaena loureiri	จันทน์ผา	tree(s)	-	2500
Duranta erecta	เทียนทอง	pot(s)	-	15
Euphorbia pulcherrima	คริสมาสต์	tree(s)	-	25
Ficus annulata	ไทรอินโด	tree(s)	-	140
Ficus benjamina	ไทรย้อยใบแหลม	tree(s)	-	140
Ficus microcarpa	ไทรทอง	tree(s)	-	140
Ficus sp.	ไทรเกาหลี	tree(s)	-	140
Gardenia jasminoides.	พุดศุภโชค	pot(s)	-	6
Graptophyllum pictum	ใบทอง	tree(s)	-	200

Plant species		Unit	Monetary benefits	
			Edible plants	Ornamental plants
			THB/kg	THB/Unit *
Heliconia spp.	ธรรมรักษา	pot(s)	-	35
Hibiscus spp.	ชบา	pot(s)	-	5
Homalomena rubescens	ว่านเสน่ห์จันทร์แดง	tree(s)	-	45
Hymenocallis littoralis	พลับพลึงตีนเป็ด	pot(s)	-	25
Ixora finlaysoniana	เข็มพวงขาว	tree(s)	-	10
Ixora longifolia	เข็มเศรษฐีมาเลเซีย	tree(s)	-	10
Ixora macrothyrsa	เข็มเศรษฐี	tree(s)	-	10
Ixora chinensis	เข็มญี่ปุ่น	tree(s)	-	10
Mangifera indica	มะม่วง	tree(s), kg	24.7	820
Ocimum tenuiflorum	กะเพรา	m^2, kg	14.56	27
Phymatosorus scolopendria	เฟิร์นหลังสวน	kg	-	34
Millingtonia hortensis	ปีบ	tree(s)	-	2205
Mimusops elengi	พิกุล	tree(s)	-	2205
Moringa oleifera	มะรุม	tree(s), kg	17.14	545
Murraya paniculata	แก้ว	pot(s)	-	180
Nephrolepis cordifolia	เฟิร์นใบมะขาม	pot(s)	-	34
Ocimum × *africanum*	แมงลัก	m^2, kg	54.03	27
Ocimum basilicum	โหระพา	m^2, kg	15.4	27
Pandanus amaryllifolius	เตยหอม	pot(s), kg	19	10
Pandanus tectorius	การะเกด	pot(s)	-	11
Philodendron xanadu	ซานาดู	tree(s)	-	100
Pisonia grandis	แสงจันทร์	pot(s)	-	1045
Plumeria rubra	ลั่นทม	tree(s)	-	2205
Polyalthia longifolia	อโศกอินเดีย	tree(s)	-	130
Pseuderanthemum carruthersii	ใบนาก	tree(s)	-	200
Pseuderanthemum crenulatum	เข็มม่วง	tree(s)	-	10
Ptychosperma macarthurii	หมากเขียว	tree(s)	-	147
Ravenala madagascariensis	กล้วยพัด	tree(s)	-	2500
Rhapis excelsa	จั๋ง	clump(s)	-	150
Ruellia squarrosa	ต้อยติ่งฝรั่ง	tree(s)	-	12
Sansevieria spp.	ลิ้นมังกร	pot(s)	-	25
Spathiphyllum spp.	เดหลี	pot(s)	-	35
Epipremnum aureum	พลูด่าง	tree(s)	-	15
Tabebuia aurea	เหลืองปรีดียาธร	tree(s)	-	2205
Tabernaemontana pandacaqui	พุดร้อยมาลัย	pot(s)	-	6
Thrinax parviflora	ปาล์มสะดือเขียว	tree(s)	-	147
Ficus pumila	ตีนตุ๊กแก	tree(s)	-	300
Adonidia merrillii	หมากนวล	tree(s)	-	147
Chrysopogon zizanioides	หญ้าแฝก	m^2	-	30

Plant species		Unit	Monetary benefits	
			Edible plants	Ornamental plants
			THB/kg	THB/Unit *
Sphagneticola trilobata	กระดุมทอง	pot(s)	-	8
Wodyetia bifurcata	ปาล์มหางกระรอก	tree(s)	-	147
Wrightia religiosa	โมกบ้าน	pot(s)	-	100

Note: * Units of monetary benefits of ornamental plants in this study are presented in THB/tree(s), THB/pot(s), THB/clump(s), THB/m^2, and THB/kg depended on the unit type of each ornamental plant that was recorded. Data modified from the (Bureau of Agricultural Commodities Promotion and Management, 2017)

APPENDIX D
QUESTIONS FOR SEMI-STRUCTURE INTERVIEW FOR CULTURAL SERVICE ASSESSMENT

Part I: Accessibility and quantity standards

1. What type of visitors is usually found on the green roof?
2. How many people visit the green roof per day?

Part II: Quality standards

1. What type of utilization is usually observed on the green roof?
2. How do you keep the green roof clean?
3. How do you take care the vegetation? (e.g. watering, fertilization, and trimming) and how often do you do the vegetation maintenance activities?
   Do you have the safety measures for your green roof?

APPENDIX E
INDICATORS AND REFERENCE VALUES USED IN THE RAPID ASSESSMENT CHECKLIST

No	Ecosystem service	Direct indicator	Proxy indicator	Reference value (indicator score)	References
1	Gas regulation	Carbon sequestration	Green ratio	≥ 75% (1), 50-74% of all area (0.5), 25-49% (0.25), < 25% (0) of all area	Pollution Control Department (2013)
		Carbon storage	Woody plants	Yes (1), No (0.5)	Whittinghill et al. (2014)
			Substrate depth	> 15 cm (1), ≤ 15 cm (0.5)	Banting et al., 2005
			Fertilizer application	Yes (1), No (0)	Rowe, Monterusso, and Rugh (2006)
			Drainage	Yes (1), No (0)	Whittinghill et al. (2014)
			Number of trees	≥ 1 tree per 100 m^2 of opened area (1), < 1 tree per 100 m^2 of opened area (0)	Pollution Control Department (2013)
2	Climate regulation	Building temperature	Substrate depth	> 15 cm (1), ≤ 15 cm (0.5)	Pianella et al. (2017)
			Area exposed to sunlight	< 50% (1), ≥ 50% of all area (0)	Pollution Control Department (2013)
			Trees (provide shade for the building)	≥ 1 per 4 m of each side of building (1), < 1 per 4 m of each side of building (0)	Pollution Control Department (2013)
3	Storm water regulation and disturbance prevention	Water holding capacity (WHC)	Substrate depth	> 15 cm (1), ≤ 15 cm (0.5)	Mentens, Raes, and Hermy (2006)
	Flood prevention by runoff mitigation	Rainfall-retention capability	Storage reservoirs and ponds	Yes (1), No (0)	Mentens et al. (2006)
			Green area	More green area, higher potential for runoff reduction (Min-Max)	Mentens et al. (2006)
			Permeable area	> 5% (1), ≤ 5% of total area (0)	Pollution Control Department (2013)
4	Waste treatment	SO_2 concentration	Green roof types	Intensive GR (1), extensive GR (0.5)	Yang et al. (2008)
	Air pollution	NO_2 concentration	Vegetation growth forms	tree (1), shrub (0.5), herb/grass (0.25)	Currie and Bass (2008)

No	Ecosystem service	Direct indicator	Proxy indicator	Reference value (indicator score)	References
		PM_{10} O_3 CO	Vegetation species	evergreen species (1), deciduous species (0.5)	Currie and Bass (2008)
	Water purification	Stormwater quality	Phytoremediation potential of plant	Yes (1), No (0)	Vijayaraghavan and Joshi (2014)
			Fertilization	Yes (0), No (1)	Rowe (2011)
			Pesticide used	Yes (0), No (1)	Rowe (2011)
			Substrate depth	> 15 cm (1), ≤ 15 cm (0.5)	Rowe (2011)
			pH	pH 6–8.5 (1), pH < 6 or > 8.5 (0)	Landschaftsbau eV (2008)
5	Pollination	Pollinator diversity	Flowing plants	Yes (1), No (0)	Home Garden Seed Association (2015)
		Insect pollinators	Plants with seasonal variety	Yes (1), No (0)	U.S. Fish and Wildlife (2014)
		Bird pollinators	Pesticides use	Yes (0), No (1)	Home Garden Seed Association (2015)
			Water sources	Yes (1), No (0)	Home Garden Seed Association (2015)
			Nesting opportunities	Yes (1), No (0)	Home Garden Seed Association (2015)
			Undisturbed soil	Yes (1), No (0)	Home Garden Seed Association (2015)
			Green roof height	< 5 building levels (Bee & wasp) (1), ≥ 5 building levels (Bee & wasp) (0)	MacIvor (2016)
6	Food provision	Food production	Edible plants	Yes (1), No (0)	Hurley and Emery (2018)
			Available crop yields	Yes (1), No (0)	Egoh et al. (2012)
			Light soil	Yes (1), No (0)	FoodShare (2015) (2015)
			Substrate depth	< 12 inches (1), ≥ 12 inches (0)	FoodShare (2015) (2015)
			Sunlight hours on the roof	10 hours (1), ≠ 10 hours (0)	Germain et al. (2008)
			Sun protection	Yes (1), No (0)	FoodShare (2015) (2015)
			A wind breaker	Yes (1), No (0)	Germain et al. (2008)
			Water access (ex. water tap)	Yes (1), No (0)	FoodShare (2015) (2015)
			Drip irrigation system	Yes (1), No (0)	FoodShare (2015) (2015)
			Fertilizer uses	Yes (1), No (0)	FoodShare (2015) (2015)
			Occurrence of crop damage by animals (birds)	Yes (0), No (1)	Fernandez-Cañero and González-Redondo (2010)
7	Aesthetic	Landscape aesthetics	Messy appearance	Yes (0), No (1)	Jungels et al. (2013)
			Planting systems	Monoculture (0) polyculture (1)	Cook-Patton and Bauerle (2012)

No	Ecosystem service	Direct indicator	Proxy indicator	Reference value (indicator score)	References
			Using evergreens and flowering plants that have a long blooming season	Yes (1), No (0)	Getter and Rowe (2006)
8	Recreation	Use of green roofs for recreation by the public	Number of trees	≥ 1 tree per 50 m^2 of opened area (1), < 1 tree per 50 m^2 of opened area (0)	Office of Natural Resources and Environmental Policy and Planning (2014)
			Number of plants that provide shade for the building in each building side	≥ 1 per 4 m of each side (1), < 1 per 4 m of each side (0)	Pollution Control Department (2013)
			Permeable surface area	≥ 75% (1), < 75% (0) of all area	Office of Natural Resources and Environmental Policy and Planning (2014)
			Vertical structure of plant	> 50% (1), ≤ 50% (0)	Office of Natural Resources and Environmental Policy and Planning (2014)
			Number of visitors	Depend on number (Min-Max)	Office of Natural Resources and Environmental Policy and Planning (2014)
			Facility for recreation	Yes (1), No (0)	Bieling and Plieninger (2013)
			Accessibility (permission to use green roof)	Yes (1), No (0)	Office of Natural Resources and Environmental Policy and Planning (2014)
9	Science & education	Uses of green roofs in educational aspects (for example, excursion)	Facility for education	Yes (1), No (0)	Ghermandi and Fichtman (2015)
			Education activities	Yes (1), No (0)	Ghermandi and Fichtman (2015)
10	Habitat provision	Species diversity and richness of faunas	Green roof types	Intensive GR (1), extensive GR (0.5)	Hui (2011)
			Green roof height	< 15 building levels (< 50 m) (1), ≥ 15 building levels (< 50 m) (0.5)	Wang et al. (2017)
			Depth of substrate	> 15 cm (1), ≤ 15 cm (0.5)	Hui (2011)

No	Ecosystem service	Direct indicator	Proxy indicator	Reference value (indicator score)	References
			Topographic variation	Yes (1), No (0)	Torrance et al. (2013)
			A continuous coverage of substrate	> 75% (1), ≤ 75% (0)	Banting (2005)
			Planted area	> 1,100 m^2 (1), ≤ 1,100 m^2 (0)	Wang et al. (2017)
			Vegetation cover	More green area, higher potential for habitat provision (Min-Max)	Williams et al. (2014)
			Plant species selection	Exotic species (0.25), native species (0.5), Both (1)	Hui (2011)
			Perching habitat	Yes (1), No (0)	Torrance et al. (2013)
			Nesting opportunities	Yes (1), No (0)	Torrance et al. (2013)
			Water sources	Yes (1), No (0)	Torrance et al. (2013)
			Connectivity to natural green area	Yes (1), No (0)	Hui (2011)

APPENDIX F
QUESTIONNAIRE FOR INVESTIGATING PERCEPTION ON GREEN ROOFS

Part I: General information

1. Gender ○ Male ○ Female
2. Age ____________ years old
3. Occupation ○ Student ○ Officer ○ Engineer
   ○ Architect ○ Other ____________________
4. Education level ○ High school graduate, diploma or the equivalent
   ○ Bachelor's degree ○ Master's degree
   ○ Doctorate degree ○ Other ____________
5. Income (per month) ○ <5,000 THB ○ 5,000-9,999 THB
   ○ 10,000-19,999 THB ○ 20,000-29,999 THB
   ○ 30,000-39,999 THB ○ ≥40,000
6. Resident type ○ Single-family house ○ Townhouse
   ○ Condominium ○ Other ____________

Part II: Perception on the utilization of green roofs and the priority of green roof ecosystem services

1. Do you know a green roof? ○ Yes ○ No (Please go to question 3)
2. What is the definition of the green roof?
   ☐ The project of compilation of recycled UHT milk boxes in order to be used for roofing
   ☐ The conventional roof that is painted with green color
   ☐ The rooftop that is designed for saving building energy and mitigating the environmental problems and is constructed using the concepts of Green architecture, or Clean Architecture, and Clean Technology
   ☐ The rooftop that has the construction of vegetation and growing medium
3. The green roof or rooftop garden is the installation of vegetation and growing medium on the rooftop of building (Oberndorfer et al., 2007)

In your opinion, what is/are the benefits from green roof implementation?

☐ Increasing green space area ☐ Transforming abandoned area into useful area
☐ Solving environmental problems ☐ Increasing aesthetic value of the building
☐ Being area for conduction of urban agriculture
☐ Encouraging people to live closer to nature
☐ Being community garden for doing activities together
☐ Other ....

4. Please give the following 10 green roof ecosystem services the scores (1-10 points) depending on your opinion about the important level of each service.

Ecosystem services	Scores (1=the lowest importance, 10=the highest importance)
Gas regulation	
Climate regulation	
Waste treatment	
Stormwater regulation	
Habitat function	
Recreation	
Pollination	
Aesthetic information	
Food provision	
Education	

5. In your opinion, what is/are the disadvantage of green roof implementation?
   ☐ High installation and maintenance cost
   ☐ Facilitating disease transmission from any annoying animals
   ☐ Negative effect on building structure
   ☐ Other ....
6. Have you ever visited the green roof?
   ○ Yes: What activity do you do on the green roof?
      ☐ Exercise ☐ Recreation ☐ Urban agriculture
      ☐ Educational area ☐ Skywalk ☐ Other ....
   ○ No: Please go to question 8
7. How often do you visit the green roof? .... ○ time(s)/week ○ time(s)/month
8. What is/are the reason(s) you have never visited the green roof?
   ☐ Do not know where the green roof is ☐ No green roof on the building
   ☐ Difficulty to access ☐ Concern about safety
   ☐ No important facility ☐ Other ....

Part III: Perception on decision of green roof construction

1. If there are spaces in your residence for increasing green area, do you want to construct the green roof?
   ○ Yes: because ....
   ○ No: because ....
2. Do you need more the green roof at your university/workplace?
   ○ Yes: because ....
   ○ No: because ....
3. If you are the building owner (e.g. a department store, condominium, hotel, and office), do you want to construct the green roof at your building?
   ○ Yes: because ....
   ○ No: because ....
4. In your opinion, what is/are the limitations of green roof implementation?
   ☐ High installation and maintenance costs
   ☐ Limited loading capacity of the building
   ☐ Lack of the knowledge about green roof construction
   ☐ Other ....
5. What support do you need for green roof construction?
   ☐ Providing technical knowledge about green roofs
   ☐ Suggestion for planting vegetation on the green roofs
   ☐ The green roof at the government office where can be a case study for the public
   ☐ Creating policies and incentives for green roof support, such as tax deduction for entrepreneurs who have buildings with green roofs
   ☐ Other ....
6. In your opinion, which knowledge areas should be involved in the green roof construction?
   ☐ Architecture ☐ Engineering ☐ Ecology and Environmental sciences
   ☐ Other ....

APPENDIX G
CRITERIA USED IN ALPHABET CARDS IN THE 2D GREEN ROOF BOARD GAME

A: Trees have higher potential in carbon storage than other plant types; therefore, there should be trees more than 15 units on your green roof.

B: Vegetation on your green roof should include more than 3 plant types (Tree/Shrub/Herb/Grass) in order to mimic the natural ecosystem.

C: Trees with high potential in carbon storage including Mango (มะม่วง) Queen's Flower (อินทนิลน้ำ) และ Hibiscus (ชบา) should be planted on your green roof at least 2 units (Green roof card no. 1).

D: Trees with high potential in absorption of air pollution including Black wattle (กระถินณรงค์) และ Spanish Cherry (พิกุล) should be planted on your green roof at least 2 units (Green roof card no. 3).

E: In order to reduce heat in the building, plants that provide shade for the building should be more than 7 trees in each building side.

F: In order to reduce water runoff, permeable surface area including soil, gravel, planting/green area, and grass should be more than 19 units (75% of total rooftop area).

G: According to the concept of green architecture and clean technology, there should be installation of solar cell at least 1 unit on your green roof. (Green roof card no.4)

H: Your green roof can play a role as an urban agricultural space; therefore, crops (e.g. vegetables and fruits) should be found at least 2 units (Green roof card no.5 or 6).

I: In order to make more profit from your green roof, beekeeping should be found on your green roof at least 1 unit. (Green roof card no.7)

J: Timber from trees is one of the provisioning services on green roof; therefore, plants that can be used for making furniture should be grown on the green roof, such as bamboo. (Green roof card no.8)

K: Your green roof should be opened to the public for using as a recreational space of the building.

L: Your green roof should provide aesthetic value; therefore, flowering plants should be grown on the green roof at least 2 units (Green roof card no.11, 12, 15, and 16).

M: Your green roof should provide core facilities for recreation, e.g. tables, chairs, sunshade, footpath, and light bulbs (Green roof card no.9, 10, 11, 12, 14, and 15).

N: There should be a swimming pool on your green roof for recreation and exercise. (Green roof card no.10)

O: There should be a playground on your green roof for recreation and exercise. (Green roof card no.9)

P: There should be a rooftop learning center on your green roof for providing educational values about urban ecosystem. (Green roof card no.11)

Q: There should be education activities on your green roof, such as green roof tour for learning plant species found in urban ecosystem. (Green roof card no.11)

R: A green roof should have area of continuous coverage substrate more than 19 units (75% of total rooftop area) to provide habitat for animals.

S: Polyculture (more than 1 plant species found) should be established on your green roof to enhance diversity of plants and then the high plant diversity can facilitate ecosystem stable and resilience of the green roof.

T: Storage reservoirs should be installed on your green roof in order to provide water sources for animals. (Green roof card no.14 and 15)

U: The potential in animal conservation can be increased if a green roof is located near other green spaces. This is because the green roof can facilitate the mobility of animals from one green space to another green space.

V: In order to provide habitat for animals, such as birds, bird feeding, and natural bird food sources should be installed on your green roof. (Green roof card no.13)

W: In order to provide habitat for animals, such as birds, water sources or a bird bath should be installed on your green roof. (Green roof card no.10, 14, and 15)

X: The government announces the policy about increasing green space in the city. Therefore, the building that has a green roof will get the reward.

Y: A building owner proposes a suggestion for publicizing green roof technology.

APPENDIX H
DATA RECORDING SHEETS AND RAPID ASSESSMENT QUESTIONS USED IN THE 2D GREEN ROOF BOARD GAME

1. Questions in data record sheets for the first scenario

1.1 What are the objectives of your green roof construction?

1.2 What is the concept that you used for designing and creating your green roof?

1.3 Elements of your green roof: The number of each green roof card that was used on the green roof.

2. Questions in data record sheets for the second scenario

2.1 After playing the 1st round, what do you want to improve in ecosystem services on your green roof?

2.2 What is the concept or techniques that you used for improving or enhancing ecosystem services on your green roof?

Table 1H Rapid assessment for green roof ecosystem services

No.	Indicators	Data
1	The ratio between green roof area and total rooftop area (%)	☐ More than 75% ☐ Less than 75%
2	The ratio between the continuous coverage of substrate area and total green roof area (%)	☐ More than 75% ☐ Less than 75%
3	Do you have storage reservoirs on your green roof?	☐ Yes ☐ No
4	Do you have a green area near your green roof?	☐ Yes ☐ No
5	Do you have an undisturbed soil area on your green roof?	☐ Yes ☐ No
6	Does your green roof provide nesting opportunities? (e.g. Tall grasses and shrubs, Birdhouses, Logs and branches, Open soil areas, or Bee nest boxes)	☐ Yes ☐ No
7	Do you have woody plants on your green roof?	☐ Yes ☐ No
8	Diversity of plants used on your green roof	☐ Monoculture ☐ Polyculture
9	Do you have flowering plants on your green roof?	☐ Yes ☐ No
10	Does your green roof have more than 7 trees in each building side?	☐ Yes ☐ No
11	Do you have crops on your green roof?	☐ Yes ☐ No
12	Do you allow other people to use your green roof as a community garden?	☐ Yes ☐ No
13	Do you use the fertilizer for enhancing plant growth on your green roof?	☐ Yes ☐ No
14	Do you use agrichemical on your green roof?	☐ Yes ☐ No
15	Do you use pesticides on your green roof?	☐ Yes ☐ No
16	Frequency of watering plants	(time(s)/day)

No.	Indicators	Data	
17	Do you have core facilities for recreation on your green roof? (e.g. tables, chairs, sunshade, footpath, light bulbs, playground, a swimming pool)	☐ Yes	☐ No
18	Do you have facilities for education on your green roof? (If yes) What are your facilities for education on your green roof?	☐ Yes	☐ No
19	Do you have an education activity on your green roof? (If yes) Please indicate examples of education activity on your green roof.	☐ Yes	☐ No

APPENDIX I
PLANT SPECIES FOUND ON SEVEN GREEN ROOFS, BANGKOK, THAILAND

Table 1I Tree species found on the green roofs in this study

Green roofs	Scientific name	Thai name	Number of individuals
APR	*Adonidia merrillii*	หมากนวล	21
	Cerbera odollam	ตีนเป็ดน้ำ	8
	Ficus benjamina	ไทรย้อยใบแหลม	10
	Moringa oleifera	มะรุม	1
	Murraya paniculate	แก้ว	35
	Plumeria rubra	ลั่นทม	4
	Wrightia religiosa	โมกบ้าน	5
ASH	*Acacia auriculiformis*	กระถินณรงค์	5
	Artabotrys siamensis	การเวก	8
	Bambusa multiplex	ไผ่เลี้ยง	112
	Caryota urens	เต่าร้าง	6
	Cocos nucifera	มะพร้าว	35
	Dracaena loureiri	จันทน์ผา	4
	Dypsis lutescens	หมากเหลือง	123
	Ficus benjamina	ไทรย้อยใบแหลม	21
	Polyalthia longifolia	อโศกอินเดีย	2
	Pritchardia pacifica	ปาล์มพัด	14
	Ptychosperma macarthurii	หมากเขียว	25
	Rhapis excelsa	จั๋ง	58
	Thrinax parviflora	ปาล์มสะดือเขียว	1
MHT	*Millingtonia hortensis*	ปีบ	8
	Plumeria rubra	ลั่นทม	11
	Ptychosperma macarthurii	หมากเขียว	45
	Tabebuia aurea	เหลืองปรีดิยาธร	4
MTK	*Bambusa multiplex*	ไผ่เลี้ยง	144
	Copernicia prunifera	ปาล์มแว็กซ์	3
	Dracaena loureiri	จันทน์ผา	1
	Ficus annulata	ไทรอินโด	16
	Mimusops elengi	พิกุล	2
	Plumeria rubra	ลั่นทม	5
	Wodyetia bifurcate	ปาล์มหางกระรอก	34
SGT	*Acacia auriculiformis*	กระถินณรงค์	1
	Dypsis lutescens	หมากเหลือง	3
	Ficus benjamina	ไทรย้อยใบแหลม	3
	Plumeria rubra	ลั่นทม	1

Green roofs	Scientific name	Thai name	Number of individuals
SXV	*Artabotrys siamensis*	การเวก	24
	Ptychosperma macarthurii	หมากเขียว	15

Table 2I Shrub species found on the green roofs in this study

Green roofs	Scientific name	Thai name	Number of individuals
APR	*Bougainvillea spectabilis*	เฟื่องฟ้า	13
	Codiaeum variegatum	โกสน	6
	Euphorbia pulcherrima	คริสมาสต์	1
	Gardenia jasminoides	พุดศุภโชค	24
	Hibiscus spp.	ชบา	17
	Ixora chinensis	เข็มญี่ปุ่น	48
	Ixora longifolia	เข็มเศรษฐีมาเลเซีย	3
	Ixora macrothyrsa	เข็มเศรษฐี	47
	Pseuderanthemum crenulatum	เข็มม่วง	34
	Tabernaemontana pandacaqui	พุดร้อยมาลัย	13
ASH	*Cordyline fruticose*	หมากผู้หมากเมีย	14
	Ixora finlaysoniana	เข็มพวงขาว	30
	Wrightia religiosa	โมกบ้าน	1
MHT	*Graptophyllum pictum*	ใบทอง	62
	Ixora chinensis	เข็มญี่ปุ่น	181
	Pseuderanthemum carruthersii	ใบนาก	18
MTK	*Bougainvillea spectabilis*	เฟื่องฟ้า	267
	Duranta erecta	เทียนทอง	2
	Ehretia microphylla	ชาฮกเกี้ยน	168
	Ficus microcarpa	ไทรทอง	24
	Ficus sp.	ไทรเกาหลี	95
	Gardenia jasminoides	พุดศุภโชค	12
	Ixora chinensis	เข็มญี่ปุ่น	480
	Ixora macrothyrsa	เข็มเศรษฐี	161
	Wrightia religiosa	โมกบ้าน	19
SGT	*Acacia auriculiformis*	กระถินณรงค์	1
	Bougainvillea spectabilis	เฟื่องฟ้า	4
	Ficus sp.	ไทรเกาหลี	14
	Ixora longifolia	เข็มเศรษฐีมาเลเซีย	1
	Ixora macrothyrsa	เข็มเศรษฐี	2
	Mangifera indica	มะม่วง	4
	Murraya paniculate	แก้ว	2
	Pisonia grandis	แสงจันทร์	1
SXV	*Bougainvillea spectabilis*	เฟื่องฟ้า	4
	Ficus sp.	ไทรเกาหลี	2
	Pisonia grandis	แสงจันทร์	8

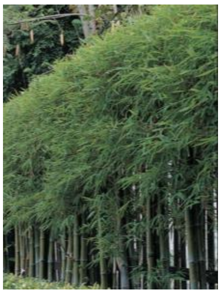
Green roofs	Scientific name	Thai name	Number of individuals
	Wrightia religiosa	โมกบ้าน	34

Table 3I Herb species found on seven green roofs

Green roofs	Scientific name	Thai name	Cover area (m^2)	% Plant cover on green roof
APR	*Alocasia macrorrhizos*	กระดาด	2.22	2.96
	Callisia fragrans	กวนอิมพันมือ	6.84	9.12
	Clitoria ternatea	อัญชัน	2.25	3.00
	Cynodon dactylon	หญ้าเบอร์มิวดา	35.60	47.47
	Dieffenbachia seguine	ช้างเผือก	0.74	0.99
	Homalomena rubescens	ว่านเสน่ห์จันทร์แดง	5.18	6.91
	Hymenocallis littoralis	พลับพลึงตีนเป็ด	13.24	17.65
	Philodendron xanadu	ซานาดู	1.90	2.53
	Ruellia squarrosa	ต้อยติ่งฝรั่ง	7.03	9.37
ASH	*Aechmea fasciata*	สับปะรดสี	1.13	0.22
	Aerva sanguinolenta	แดงชาลี	3.15	0.61
	Asplenium nidus	เฟิร์นข้าหลวง	10.18	1.97
	Asystasia gangetica	บุษบาริมทาง ใบด่าง	7.79	1.51
	Axonopus compressus	หญ้ามาเลเซีย	270.67	52.37
	Cheilocostus speciosus	เอื้องอินโด	9.70	1.88
	Chlorophytum laxum	เศรษฐีเรือนนอก	3.31	0.64
	Dracaena surculosa	ไผ่ฟิลิปปินส์	6.30	1.22
	Epipremnum aureum	พลูด่าง	138.74	26.84
	Heliconia spp.	ธรรมรักษา ก้ามกุ้ง	29.10	5.63
	Hymenocallis littoralis	พลับพลึงตีนเป็ด	17.62	3.41
	Nephrolepis cordifolia	เฟิร์นใบมะขาม	1.49	0.29
	Pandanus tectorius	การะเกด	6.30	1.22
	Phymatosorus scolopendria	เฟิร์นหลังสวน	8.00	1.55
	Ruellia squarrosa	ต้อยติ่งฝรั่ง	1.49	0.29
	Sansevieria spp.	ลิ้นมังกร	1.89	0.37
MHT	*Hymenocallis littoralis*	พลับพลึงตีนเป็ด	29.84	57.56
	Phymatosorus scolopendria	เฟิร์นหลังสวน	22.00	42.44
MTK	*Epipremnum aureum*	พลูด่าง	21.25	44.41
	Ficus pumila	ตีนตุ๊กแก	3.90	8.15
	Phymatosorus scolopendria	เฟิร์นหลังสวน	8.70	18.18
	Ruellia squarrosa	ต้อยติ่งฝรั่ง	12.32	25.74
	Spathiphyllum spp.	เดหลี	1.68	3.51
SGK	*Chrysopogon zizanioides*	หญ้าแฝก	18.11	6.26
	Ocimum × africanum	แมงลัก	108.72	37.58
	Ocimum basilicum	โหระพา	30.12	10.41
	Ocimum tenuiflorum	กะเพรา	123.88	42.82
	Pandanus amaryllifolius	เตยหอม	8.45	2.92

Green roofs	Scientific name	Thai name	Cover area (m^2)	% Plant cover on green roof
SGT	*Hymenocallis littoralis*	พลับพลึงตีนเป็ด	2.26	66.67
	Sphagneticola trilobata	กระดุมทอง	1.13	33.33

Table 4I Plant species found on seven green roofs

Plant type: Tree		
 *Acacia auriculiformis* (กระถินณรงค์) (Source: http://agkc.lib.ku.ac.th/ plantwebsite/webpage/Home/ SelectTypeSearch.html)	 *Artabotrys siamensis* (การเวก) (Source: http://rpplant.royalpark rajapruek.org/)	 *Bambusa multiplex* (ไผ่เลี้ยง) (Source: https://www.baanlaesuan. com/plants)
 *Caryota urens* (เต่าร้าง)	 *Cerbera odollam* (ตีนเป็ดน้ำ) (Source: http://agkc.lib.ku.ac.th/ plantwebsite/webpage/Home/ SelectTypeSearch.html)	 *Dypsis lutescens* (หมากเหลือง) (Source: https://www.baanlaesuan. com/plants)
 *Cocos nucifera* (มะพร้าว)	 *Copernicia prunifera* (ปาล์มแว็กซ์)	 *Dracaena loureiri* (จันทร์ผา)

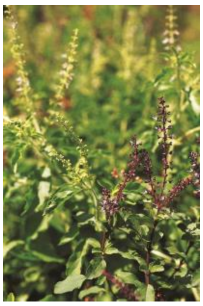
 *Ficus annulate* (ไทรอินโด)	 *Ficus benjamina* (ไทรย้อยใบแหลม)	 *Millingtonia hortensis* (ปีบ) (Source: http://agkc.lib.ku.ac.th/ plantwebsite/webpage/Home/ SelectTypeSearch.html)
 *Mimusops elengi* (พิกุล)	 *Moringa oleifera* (มะรุม) (Source: http://www.dnp.go.th/botany/)	 *Murraya paniculate* (แก้ว)
 *Plumeria rubra* (ลั่นทม) (Source: http://agkc.lib.ku.ac.th/ plantwebsite/webpage/Home/ SelectTypeSearch.html)	 *Polyalthia longifolia* (อโศกอินเดีย) (Source: http://agkc.lib.ku.ac.th/ plantwebsite/webpage/Home/ SelectTypeSearch.html)	 *Pritchardia pacifica* (ปาล์มพัด)

 *Ptychosperma macarthurii* (หมากเขียว) (Source: http://agkc.lib.ku.ac.th/plantwebsite/webpage/Home/SelectTypeSearch.html)	 *Rhapis excelsa* (จั๋ง)	 *Tabebuia aurea* (เหลืองปรีดียาธร) (Source: http://agkc.lib.ku.ac.th/plantwebsite/webpage/Home/SelectTypeSearch.html)
 *Thrinax parviflora* (ปาล์มสะดือเขียว) (Source: https://www.baanlaesuan.com/plants)	 *Adonidia merrillii* (หมากนวล) (Source: https://www.baanlaesuan.com/plants)	 *Wodyetia bifurcate* (ปาล์มหางกระรอก)
 *Wrightia religiosa* (โมกบ้าน) (Source: http://agkc.lib.ku.ac.th/plantwebsite/webpage/Home/SelectTypeSearch.html)		

Plant type: Shrub		
 *Acacia auriculiformis* (กระถินณรงค์) (Source: http://agkc.lib.ku.ac.th/ plantwebsite/webpage/Home/ SelectTypeSearch.html)	 *Bougainvillea spectabilis* (เฟื่องฟ้า)	 *Ehretia microphylla* (ชาฮกเกี้ยน)
 *Codiaeum variegatum* (โกสน)	 *Cordyline fruticose* (หมากผู้หมากเมีย)	 *Duranta erecta* (เทียนทอง)
 *Euphorbia pulcherrima* (คริสมาสต์)	 *Ficus microcarpa* (ไทรทอง)	 *Ficus* sp. (ไทรเกาหลี)
 *Gardenia jasminoides* (พุดศุภโชค)	 *Graptophyllum pictum* (ใบทอง)	 *Hibiscus* spp. (ชบา) (Source: http://agkc.lib.ku.ac.th/ plantwebsite/webpage/Home/ SelectTypeSearch.html)

 *Ixora finlaysoniana* (เข็มพวงขาว)	 *Ixora longifolia* (เข็มเศรษฐีมาเลเซีย) (Source: https://www.baanlaesuan.com/plants)	 *Ixora macrothyrsa* (เข็มเศรษฐี) (Source: http://agkc.lib.ku.ac.th/plantwebsite/webpage/Home/SelectTypeSearch.html)
 *Ixora chinensis* (เข็มญี่ปุ่น)	 *Mangifera indica* (มะม่วง) (Source: https://www.baanlaesuan.com/plants)	 *Murraya paniculate* (แก้ว)
 *Pisonia grandis* (แสงจันทร์)	 *Pseuderanthemum carruthersii* (ใบนาก)	 *Pseuderanthemum crenulatum* (เข็มม่วง)
 *Rhapis excelsa* (จั๋ง)	 *Tabernaemontana pandacaqui* (พุดร้อยมาลัย)	 *Wrightia religiosa* (โมกบ้าน) (Source: http://agkc.lib.ku.ac.th/plantwebsite/webpage/Home/SelectTypeSearch.html)

Plant type: Herb		
 *Aechmea fasciata* (สับปะรดสี)	 *Aerva sanguinolenta* (แดงชาลี)	 *Dracaena surculosa* (ไผ่ฟิลิปปินส์)
 *Alocasia macrorrhizos* (กระดาด)	 *Asplenium nidus* (เฟิร์นข้าหลวง)	 *Asystasia gangetica* (บุษบาริมทาง ใบด่าง)
 *Axonopus compressus* (หญ้ามาเลเซีย) (Source: https://www.baanlaesuan.com/plants)	 *Callisia fragrans* (กวนอิมพันมือ)	 *Chlorophytum laxum* (เศรษฐีเรือนนอก) (Source: http://agkc.lib.ku.ac.th/plantwebsite/webpage/Home/SelectTypeSearch.html)
 *Clitoria ternatea* (อัญชัน)	 *Cheilocostus speciosus* (เอื้องอินโด)	 *Cynodon dactylon* (หญ้าเบอร์มิวดา) (Source: http://www.tropicalforages.info/)

 *Dieffenbachia seguine* (ช้างเผือก, สาวน้อยประแป้ง)	 *Epipremnum aureum* (พลูด่าง)	 *Heliconia* spp. (ธรรมรักษา)
 *Homalomena rubescens* (ว่านเสน่ห์จันทร์แดง)	 *Hymenocallis littoralis* (พลับพลึงตีนเป็ด) (Source: http://agkc.lib.ku.ac.th/plantwebsite/webpage/Home/SelectTypeSearch.html)	 *Phymatosorus scolopendria* (เฟิร์นหลังสวน)
 *Nephrolepis cordifolia* (เฟิร์นใบมะขาม)	 *Ocimum* × *africanum* (แมงลัก) (Source: https://species.wikimedia.org/)	 *Ocimum basilicum* (โหระพา) (Source: https://www.baanlaesuan.com/plants)
 *Ocimum tenuiflorum* (กะเพรา) (Source: https://www.baanlaesuan.com/plants)	 *Pandanus amaryllifolius* (เตยหอม)	 *Pandanus tectorius* (การะเกด) (Source: https://www.baanlaesuan.com/plants)

 *Philodendron xanadu* (ซานาดู)	 *Ruellia squarrosa* (ต้อยติ่งฝรั่ง)	 *Sansevieria* spp. (ลิ้นมังกร)
 *Spathiphyllum* spp. (เดหลี)	 *Ficus pumila* (ตีนตุ๊กแก)	 *Chrysopogon zizanioides* (หญ้าแฝก)
 *Sphagneticola trilobata* (กระดุมทอง) (Source: http://agkc.lib.ku.ac.th/ plantwebsite/webpage/Home/ SelectTypeSearch.html)		

APPENDIX J
COVER AREA OF PLANT SPECIES IN EACH USE CATEGORY FOUND ON SEVEN GREEN ROOFS, BANGKOK, THAILAND

Table 1J Species composition of each use category found on the green roofs in this study

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
Edible plants	*Clitoria ternatea*	อัญชัน	2.25	-	-	-	-	-	-
	Cocos nucifera	มะพร้าว	-	427.26	-	-	-	-	-
	Mangifera indica	มะม่วง	-	-	-	-	-	4.52	-
	Moringa oleifera	มะรุม	19.63	-	-	-	-	-	-
	Ocimum × africanum	แมงลัก	-	-	-	-	108.72	-	-
	Ocimum basilicum	โหระพา	-	-	-	-	30.12	-	-
	Ocimum tenuiflorum	กะเพรา	-	-	-	-	123.88	-	-
	Pandanus amaryllifolius	เตยหอม	-	-	-	-	8.45	-	-
Medicinal plant	*Adonidia merrillii*	หมากนวล	16.49	-	-	-	-	-	-
	Alocasia macrorrhizos	กระดาด	2.22	-	-	-	-	-	-
	Artabotrys siamensis	การเวก	-	269.39	-	-	-	-	301.59
	Asplenium nidus	เฟิร์นข้าหลวง	-	10.18	-	-	-	-	-
	Asystasia gangetica	บุษบาริมทาง ใบต่าง	-	7.79	-	-	-	-	-
	Bambusa sp.	ไผ่	-	2.75	-	12.57	-	-	-
	Bougainvillea spectabilis	เฟื่องฟ้า	12.52	-	-	36.84	-	2.54	3.14
	Caryota urens	เต่าร้าง	-	10.60	-	-	-	-	-
	Cerbera odollam	ตีนเป็ดน้ำ	76.97	-	-	-	-	-	-
	Cheilocostus speciosus	เอื้องอินโด	-	9.70	-	-	-	-	-

Table 1J (continued)

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Chrysopogon zizanioides	หญ้าแฝก	-	-	-	-	18.11	-	-
	Clitoria ternatea	อัญชัน	2.25	-	-	-	-	-	-
	Cocos nucifera	มะพร้าว	-	427.26	-	-	-	-	-
	Codiaeum variegatum	โกสน	1.28	-	-	-	-	-	-
	Cordyline fruticosa	หมากผู้หมากเมีย หางหงส์	-	11.00	-	-	-	-	-
	Dracaena loureirin	จันทน์ผา	-	12.57	-	1.13	-	-	-
	Duranta erecta	เทียนทอง	-	-	-	0.07	-	-	-
	Dypsis lutescens	หมากเหลือง	-	96.29	-	-	-	0.79	-
	Ehretia microphylla	ชาฮกเกี้ยน	-	-	-	12.32	-	-	-
	Ficus benjamina	ไทรย้อยใบแหลม	30.04	1570.80	-	-	-	5.30	1.57
	Ficus pumila	ตีนตุ๊กแก	-	-	-	-	-	-	-
	Ficus sp.	ไทรเกาหลี	-	-	-	13.15	-	12.37	-
	Graptophyllum pictum	ใบทอง	-	-	16.56	-	-	-	-
	Hibiscus spp.	ชบา	6.76	-	-	9.90	-	-	-
	Homalomena rubescens	ว่านเสน่ห์จันทร์แดง	5.18	-	-	-	-	-	-
	Hymenocallis littoralis	พลับพลึงตีนเป็ด	13.24	17.62	29.84	-	-	2.26	-
	Ixora finlaysoniana	เข็มพวงขาว	-	23.56	-	-	-	-	-
	Ixora macrothyrsa	เข็มเศรษฐี	31.11	-	-	20.08	-	2.26	-

Table 1J (continued)

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Mangifera indica	มะม่วง	-	-	-	-	-	4.52	-
	Melampodium divaricatum	กะเพรา	-	-	-	-	123.88	-	-
	Millingtonia hortensis	ปีบ	-	-	31.42	-	-	-	-
	Mimusops elengi	พิกุล	-	-	-	8.31	-	-	-
	Moringa oleifera	มะรุม	19.63	-	-	-	-	-	-
	Murraya paniculata	แก้ว	109.96	-	-	-	-	0.06	-
	Ocimum × africanum	แมงลัก	-	-	-	-	108.72	-	-
	Ocimum basilicum	โหระพา	-	-	-	-	30.12	-	-
	Pandanus amaryllifolius	เตยหอม	-	-	-	-	8.45	-	-
	Pandanus tectorius	การะเกด	-	6.30	-	-	-	-	-
	Pisonia grandis	แสงจันทร์	-	-	-	-	-	1.77	6.28
	Plumeria rubra	ลั่นทม	50.27	-	77.75	48.11	-	3.14	-
	Pseuderanthemum carruthersii	ใบนาก	-	-	4.40	-	-	-	-
	Pseuderanthemum crenulatum	เข็มม่วง	13.52	-	-	-	-	-	-
	Ruellia squarrosa	ต้อยติ่งฝรั่ง	7.03	1.49	-	3.90	-	-	-
	Sansevieria spp.	ลิ้นมังกร	-	1.89	-	-	-	-	-
	Sphagneticola trilobata	กระดุมทอง	-	-	-	-	-	1.13	-
	Tabernaemontana pandacaqui	พุดร้อยมาลัย	17.17	-	-	-	-	-	-

Table 1J (continued)

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Wrightia religiosa	โมกบ้าน	15.71	0.79	-	1.92	-	-	26.70
Ornamental plant	*Acacia auriculaeformis*	กระถินณรงค์	-	3.93	-	-	-	2.08	-
	Adonidia merrillii	หมากนวล	16.49	-	-	-	-	-	-
	Aechmea fasciata	สับปะรดสี	-	1.13	-	-	-	-	-
	Aerva sanguinolenta	แดงชาลี	-	3.15	-	-	-	-	-
	Alocasia macrorrhizos	กระดาด	2.22	-	-	-	-	-	-
	Artabotrys siamensis	การเวก	-	269.39	-	-	-	-	301.59
	Asplenium nidus	เฟิร์นข้าหลวง	-	10.18	-	-	-	-	-
	Asystasia gangetica	บุษบาริมทาง ใบด่าง	-	7.79	-	-	-	-	-
	Axonopus compressus	หญ้ามาเลเซีย	-	270.67	-	-	-	-	-
	Bambusa sp.	ไผ่	-	2.75	-	12.57	-	-	-
	Bougainvillea spectabilis	เฟื่องฟ้า	12.52	-	-	36.84	-	2.54	3.14
	Callisia fragrans	กวนอิมพันมือ	6.84	-	-	-	-	-	-
	Caryota urens	เต่าร้าง	-	10.60	-	-	-	-	-
	Cerbera odollam	ตีนเป็ดน้ำ	-	-	-	-	-	-	-
	Cheilocostus speciosus	เอื้องอินโด	-	9.70	-	-	-	-	-
	Chlorophytum laxum	เศรษฐีเรือนนอก	-	1.66	-	-	-	-	-
	Chrysopogon zizanioides	หญ้าแฝก	-	-	-	-	18.11	-	-

Table 1J (continued)

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Clitoria ternatea	อัญชัน	2.25	-	-	-	-	-	-
	Cocos nucifera	มะพร้าว	-	427.26	-	-	-	-	-
	Codiaeum variegatum	โกสน	1.28	-	-	-	-	-	-
	Copernicia prunifera	ปาล์มแว็กซ์	-	-	-	9.42	-	-	-
	Cordyline fruticosa	หมากผู้หมากเมีย หางหงส์	-	11.00	-	-	-	-	-
	Cynodon dactylon	หญ้าเบอร์มิวดา	35.60	-	-	-	-	-	-
	Dieffenbachia seguine	ช้างเผือก	0.74	-	-	-	-	-	-
	Dracaena loureirin	จันทน์ผา	-	12.57	-	1.13	-	-	-
	Dracaena surculosa	ไผ่ฟิลิปปินส์	-	3.15	-	-	-	-	-
	Duranta erecta	เทียนทอง	-	-	-	0.07	-	-	-
	Dypsis lutescens	หมากเหลือง	-	96.29	-	-	-	0.79	-
	Ehretia microphylla	ชาฮกเกี้ยน	-	-	-	9.90	-	-	-
	Epipremnum aureum	พลูด่าง	-	138.74	-	21.25	-	-	-
	Euphorbia pulcherrima	คริสมาสต์	0.72	-	-	-	-	-	-
	Ficus annulate	ไทรอินโด	-	-	-	18.10	-	-	-

Table 1J (continued)

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Ficus benjamina	ไทรย้อยใบแหลม	30.04	1570.80	-	-	-	5.30	1.57
	Ficus microcarpa	ไทรทอง	-	-	-	8.64	-	-	-
	Ficus pumila	ตีนตุ๊กแก	-	-	-	3.90	-	-	-
	Ficus sp.	ไทรเกาหลี	-	-	-	13.15	-	12.37	-
	Gardenia jasminoides.	พุดศุภโชค	18.85	-	-	1.13	-	-	-
	Graptophyllum pictum	ใบทอง	-	-	16.56	-	-	-	-
	Heliconia spp.	ธรรมรักษา ก้ามกุ้ง	-	29.10	-	-	-	-	-
	Hibiscus spp.	ชบา	6.76	-	-	-	-	-	-
	Homalomena rubescens	ว่านเสน่ห์จันทร์แดง	5.18	-	-	-	-	-	-
	Hymenocallis littoralis	พลับพลึงตีนเป็ด	13.24	17.62	29.84	-	-	2.26	-
	Ixora chinensis	เข็มญี่ปุ่น	13.60	-	30.23	21.59	-	-	-
	Ixora finlaysoniana	เข็มพวงขาว	-	23.56	-	-	-	-	-
	Ixora longifolia	เข็มเศรษฐีมาเลเซีย	3.56	-	-	-	-	0.79	-
	Ixora macrothyrsa	เข็มเศรษฐี	31.11	-	-	20.08	-	2.26	-

Table 1J (continued)

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Mangifera indica	มะม่วง	-	-	-	-	-	4.52	-
	Melampodium divaricatum	กะเพรา	-	-	-	-	123.88	-	-
	Millingtonia hortensis	ปีบ	-	-	31.42	-	-	-	-
	Mimusops elengi	พิกุล	-	-	-	8.31	-	-	-
	Moringa oleifera	มะรุม	19.63	-	-	-	-	-	-
	Murraya paniculata	แก้ว	-	-	-	-	-	0.06	-
	Nephrolepis cordifolia	เฟิร์นใบมะขาม	-	1.49	-	-	-	-	-
	Ocimum × africanum	แมงลัก	-	-	-	-	108.72	-	-
	Ocimum basilicum	โหระพา	-	-	-	-	30.12	-	-
	Pandanus amaryllifolius	เตยหอม	-	-	-	-	8.45	-	-
	Pandanus tectorius	การะเกด	-	6.30	-	-	-	-	-
	Philodendron xanadu	ซานาดู	1.90	-	-	-	-	-	-
	Phymatosorus scolopendria	เฟิร์นหลังสวน	-	8.00	22.00	8.70	-	-	-
	Pisonia grandis	แสงจันทร์	-	-	-	-	-	1.77	6.28

Table 1J (continued)

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Plumeria rubra	ลั่นทม	50.27	-	77.75	48.11	-	3.14	-
	Polyalthia longifolia	อโศกอินเดีย	-	1.57	-	-	-	-	-
	Pritchardia pacifica	ปาล์มพัด	-	175.93	-	-	-	-	-
	Pseuderanthemum carruthersii	ใบนาก	-	-	4.40	-	-	-	-
	Pseuderanthemum crenulatum	เข็มม่วง	13.52	-	-	-	-	-	-
	Ptychosperma macarthurii	หมากเขียว	-	18.85	35.34	-	-	-	11.78
	Ravenala madagascariensis	กล้วยพัด	-	21.21	-	-	-	-	-
	Rhapis excelsa	จั๋ง	-	11.39	-	-	-	-	-
	Ruellia squarrosa	ต้อยติ่งฝรั่ง	76.97	1.49	-	12.32	-	-	-
	Sansevieria spp.	ลิ้นมังกร	-	1.89	-	-	-	-	-
	Spathiphyllum spp.	เดหลี	-	-	-	1.68	-	-	-
	Sphagneticola trilobata	กระดุมทอง	-	-	-	-	-	1.13	-
	Tabebuia aurea	เหลืองปรีดียาธร	-	-	78.54	-	-	-	-
	Tabernaemontana pandacaqui	พุดร้อยมาลัย	17.17	-	-	-	-	-	-

Table 1J (continued)

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Thrinax parviflora	ปาล์มสะคือเขียว	-	12.57	-	-	-	-	-
	Wodyetia bifurcata	ปาล์มหางกระรอก	-	-	-	129.25	-	-	-
	Wrightia religiosa	โมกบ้าน	15.71	0.79	-	1.92	-	-	26.70
Plant species for other uses	*Acacia auriculaeformis*	กระถินณรงค์	-	23.56	-	-	-	2.08	
	Artabotrys siamensis	การเวก	-	3.93	-	-	-	-	301.59
	Bambusa sp.	ไผ่	-	2.75	-	12.57	-	-	
	Chrysopogon zizanioides	หญ้าแฝก	-	-	-	-	18.11	-	
	Cocos nucifera	มะพร้าว	-	427.26	-	-	-	-	
	Mangifera indica	มะม่วง	-	-	-	-	-	4.52	
	Millingtonia hortensis	ปีบ	-	-	31.42	-	-	-	
	Mimusops elengi	พิกุล	-	-	-	8.31	-	-	
	Murraya paniculata	แก้ว	109.96	-	-	-	-	-	
	Plumeria rubra	ลั่นทม	50.27	-	77.75	48.11	-	3.14	
	Polyalthia longifolia	อโศกอินเดีย	-	1.57	-	-	-	-	

Table 1J (continued)

Type of possible utilization	Plant species	Thai name	Cover area of plant species found on green roofs (m^2)						
			APR	ASH	MHT	MTK	SGK	SGT	SXV
	Ravenala madagascariensis	กล้วยพัด	-	3.15	-	-	-	-	
	Wrightia religiosa	โมกบ้าน	15.71	0.79	-	1.92	-	-	26.70

APPENDIX K
REASONS FOR DECIDING FOR GREEN ROOF CONSTRUCTION

Reasons that the respondents decide…*	
To construct a green roof	Not to construct a green roof
• We like to plant trees. • Buildings might be more attractive and beautiful if there are green roofs. • Green roofs can help to increase green space in an urban area. • It is the way to change abandoned rooftops into a useful area. • Green roofs help to reduce pollution. • Green roofs help to decrease building temperature and save energy. • Green roofs can be used as a recreation area for doing any activities together. We do not need to go to a public park. • Green roofs might be good for the environment and it eventually involves humans. • We want to get closer to nature. • It is a very new issue and interesting. • Green roofs can help to decrease carbon dioxide in the atmosphere and global warming. • We can use green roofs to increase urban agriculture area for food security. • Taking care of green roofs might be one of the hobbies for free time. • Green roof technology is one way to conserve the environment. It can start by ourselves. • Green roofs can be used for the learning area.	• It might use a high cost for construction. • The expense will be increased in the long run. • Green roofs need high requirement of maintenance. • We have a limited area and are unable to manage that area. • Trees can bring birds and other annoying animals such as insects and mosquitoes to the surrounding area. This might cause problems with neighbors. • The weight of green roofs might affect the building structure. • There are several ways that can be used for improving the environment. • We rarely use rooftops. • There are gardens at a ground level already. • There is no area or rooftop for green roof construction. • The area on rooftops does not suitable for green roof construction. • Problems about cleanness and moisture in buildings might occur. • Knowledge about green roofs is still limited. • Green roofs do not provide real nature. • Gardening at ground level should be the best way for planting. • People access to a green roof with difficulty. So, no one used a green roof. • There is no need to construct a green roof. • We worry about safety. • There are several places for studying. It is not only a green roof. • We should better improve botanical garden than construct a green roof.

Note: * The reasons were provided by 349 respondents who participated in the online survey.

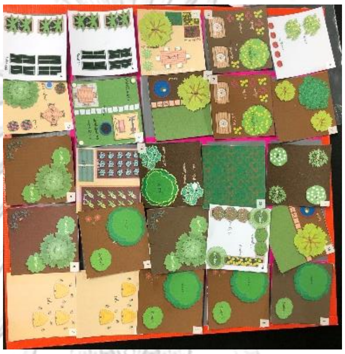
APPENDIX L
GREEN ROOF DESIGNS BY PARTICIPANTS IN GAMING SESSIONS

Table 1L Constructed green roofs in the first scenario of the first gaming session

A1 	A2 	A3 
A4 	A5 	A6 
A7 	B1 	B2 

B3 	B4 	B5 
B6 	B7 	B8 

Table 2L Constructed green roofs in the second scenario of the first gaming session

A1 	A2 	A3 
A4 	A5 	A6 
A7 	B1 	B2 
B3 	B4 	B5 

B6	B7	B8
		

Table 3L Constructed green roofs in the first scenario of the second gaming session

1 	2 	3 
4 	5 	

Table 4L Constructed green roofs in the second scenario of the second gaming session

1 	2 	3 
4 	5 	

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