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CH09 – Rooftop Systems for Urban Agriculture

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Abstract

Urban population growth, consequent competition in land use, climate change and lack of productive resources, are some of the problems that are currently stressing the necessity of a new form of agriculture free from soil exploitation and able to ensure food security to urban dwellers in the most sustainable way. In the last years, researches, international organizations and entrepreneurs all over the world identified a solution in rooftop farming, a form of building-base agriculture that may help to address not only global nutritional uncertainty, but also social, environmental and economic issues such as social exclusion, heat island effect, storm water damages and urban poverty. To achieve these goals, is definitely fundamental to improve some aspects related to rooftop farm design and management, with particular reference to technologies applied, minimization of resources use, building wastes recycle, rooftop accessibility and structural security. Local and governmental authorities' intervention will also be important in order to facilitate a future development of the sector.

Key words:

Rooftop Farming, Urban Agriculture, Soil-less System, Food Security.

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42 **1. Introduction**

43 Soil competition and high land costs in urban areas are a limitation for the development of UA, an
44 issue that can be faced by exploiting currently unused city spaces such as the roofs of residential
45 or office buildings (Gasperi, 2016). Plant cultivation on the rooftop of urban buildings – also
46 referred to as Rooftop Agriculture (Orsini, 2017) - is being therefore promoted as a way to reduce
47 the environmental footprint of the city (Sanyé-Mengual, 2015), increase its resilience to climate
48 change (Georgiadis, 2017) and overall improve the city food security (Baudoin, 2017).

49 Rooftop Agriculture is considered part of Zero-acreage farming or Z-farming concept (Specht,
50 2014; Thomaier, 2015), defined as an UA form independent from land use and integrated into
51 urban buildings. It is applied on top of constructions both in protected (*rooftop greenhouse*) and
52 non- protected (*open-air rooftop garden / farm*) conditions, with different degrees of
53 technological complexity. Differences in rooftop farming also occurs between the Global North
54 and Global South of the world, where it may vary based on growing systems applied and main
55 function related (Viljoen and Howe, 2012).

56 In developing countries, rooftop farming is characterized by low-tech plant growing systems
57 obtained by low-cost or recycled materials. Use of production inputs such as water and fertilizers
58 is also limited, as also are farmers skills, capital access and maintenance costs. The main function is
59 informal production of fresh vegetables to address food security and ameliorate nutrition,
60 although high-tech commercial rooftop farms are also currently blooming in some emerging
61 economies (Orsini, 2015).

62 Cities in richer countries are already integrating rooftop horticulture in the food market chain, as
63 demonstrated by the several experiences already existing, i.e. in North America (Specht, 2015).
64 However, urban entrepreneurs have to face with specific problems that are still constraining the
65 technological uptake on a larger scale. The main challenge is represented by initial high costs,
66 which are often threatening for investors due to long and uncertain time of return. Furthermore,
67 interdisciplinary policies are also needed in order to direct rooftop farming actors for what
68 concerns urban food security, climate change adaptation and buildings regulations (Specht, 2014).
69 Rooftop farming is a multifunctional activity that provides cities not only with food supply, but also
70 with social and environmental benefits. It may play a relevant role in waste reuse, social inclusion,
71 education and cities resilience (De Zeeuw and Drechsel, 2015). It also contributes to face specific
72 city planning problems, optimizing the use of urban spaces and containing climate change effects
73 (Dubbeling, 2017).

74 This chapter aims to go through the main aspects and challenges of rooftop farming, offering a
75 general overview of the topic.

76

77 **2. Forms of Urban Rooftop Farming**

78 Rooftop farming typologies may be classified based on different aspects such as purpose of
79 cultivation (commercial, social, environmental, therapeutical, and others), complexity of applied
80 technology (soil-based systems, hydroponics, aquaponics), type of building (school, hospital,
81 research center, office, etc.) and others, just to name some (Nasr, 2017). In this paragraph, RF
82 types will be analyzed by farm type and main objectives addressed.

83

84

85 **2.1 Farm typology: open-air rooftop farms vs. rooftop greenhouses**

86 Open-air rooftop farms or gardens are the most common forms of rooftop farming, characterized
87 by use of low-tech systems, mostly represented by soil-based solutions that employ raised beds or
88 existing green roof technologies (Thomaier, 2015). The application of low-tech soilless techniques
89 such as floating or nutrient film systems, in rooftop gardens was also suggested as a way to
90 improve performances in certain seasons or crop species (Sanyé-Mengual, 2015a).

91 Due to the absence of a physical barrier, crops may be exposed to air pollution more easily than
92 those in a rooftop greenhouse. However, it was demonstrated that the elevation may also help
93 reducing risks (Säumel, 2012). These kind of installations are less expensive and easier to create
94 compared to a greenhouse, therefore they may be applied to small-scale subsistence rooftop
95 farms to ensure family food security especially in developing countries (Bryld, 2003).

96 Rooftop greenhouses, on the contrary, require more sophisticated technologies and farming
97 techniques (Thomaier, 2015). Soil-less systems such as hydroponic, inert substrate or aeroponics,
98 are normally applied to reduce load and, at the same time, increase resource use efficiency
99 (Sanyé-Mengual, 2015b). Currently, most of the rooftop greenhouses are concentrated in US and
100 Canada, and are especially oriented to commercial food production (Sanyé-Mengual, 2015b).

101 Nonetheless, also Europe starts giving notable examples, both in commercial and research
102 projects, of which ICTA-ICP Rooftop Greenhouse Lab (RTG-Lab) in Barcelona is an example (Pons,
103 2015; Sanyé-Mengual, 2014; Sanyé-Mengual, 2015c).

104 Since a greenhouse located on an urban building can take advantage of the energy released by the
105 structure and reduce transportation miles, it may lead to a cheaper and more environmentally
106 friendly food production (Sanyé-Mengual, 2015c). On the other hand, it was estimated that a
107 rooftop greenhouse structure can have a higher environmental impact and 2.8 times higher
108 economic cost than a traditional multi-tunnel greenhouse (Sanyé-Mengual, 2015c). Moreover,
109 constructing laws concerning height limits and floor-to-area ratios may also limit the practice,
110 although some cities are moving to reduce these obstacles (Thomaier, 2015).

111

112 **2.2 Main Objective**

113 A second way to classify rooftop farming typologies is based on the main goal that the project
114 means to achieve. Together with primary purpose, secondary benefits can be reached with
115 consequent overlap of typologies.

116 Basing on the classification outlined by Thomaier (2015), rooftop farms can be divided in five
117 typologies:

- 118 - Commercial,
- 119 - Image-oriented,
- 120 - Social and educational,
- 121 - Urban living quality,
- 122 - Innovation incubator.

123 Commercial rooftop farms are business oriented start-ups with economic profitability as first aim.

124 They can operate both as “retail-affiliated” or “independent” business models (Thomaier 2015).

125 While the first type is more focused on food business, independent types may be open to
126 community and procure social benefits. According to Buehler and Junge (2016), commercial farms
127 may be subdivided in two groups based on technology applied: hydroponic systems in
128 greenhouses and soil-based open-air farms. The first type is generally limited to leafy greens,
129 tomatoes and herbs production, while soil-based farms are more adaptable to market demand,

130 growing a large variety of products. The latter is also suitable for an environmentally friendly
131 production and organic certification standards, although potentialities of hydroponic systems
132 toward sustainability of the food chain are also evident (Buehler and Junge, 2016). Most of the
133 commercial experiences are concentrated in North America, though this trend is also spreading in
134 Europe and Asia (Buehler and Junge, 2016). Due to the space needed for large-scale food
135 production, these farms are often located on top of commercial or industrial sites (Thomaier,
136 2015).

137 Image-oriented farms are represented by those cases that experience agriculture not as a main
138 objective, but as a tool for a primary activity such as a restaurant or a cafeteria. The main purpose
139 is to offer a local, fresh and sustainable meal to consumers. These rooftop farms are normally
140 integrated in the same building of main activity and especially performed with soil-based
141 techniques (Thomaier, 2015).

142 Social and educational rooftop farms have the purpose to educate to environmental and
143 sustainable production issues. They involve voluntary workers, such as students or common
144 citizens that operate without profit aim, though products may be sold for self-financing. The
145 location is normally on schools, universities and other educational or social centers (Thomaier,
146 2015).

147 Rooftop farming oriented to urban living quality has the objective to offer to residents or
148 employees a recreational space where to enjoy nature amenity. This typology is generally
149 developed by companies that want to improve working environment conditions or by real estates
150 and architecture studies that aim to develop green and sustainable housing. The farming
151 technology is usually soil-based and the products are mostly for personal use or destined to the
152 company cafeteria (Thomaier, 2015). Subsistence private gardens, such as those promoted by
153 local authorities and NGOs, can also be included in the category, helping food security and
154 ameliorating living conditions of less advantaged strata of population.

155 With rooftop farming as an innovation incubator are intended all the prototypes that aim to
156 promote new concepts of food production and consumption using innovative technologies (e.g.
157 hydroponic or aquaponic systems), and providing tours and explanations to public. Although these
158 projects are often applied on mobile and unusual structures such as containers or boats, they may
159 be reprocessed on roofs (Thomaier, 2015).

160

161 **3. Rooftop Agriculture Multifunctionality**

162 Rooftop farming is a multifunctional activity that can enrich the urban community with numerous
163 positive benefits, ranging from educational, social, environmental and economic interest. As any
164 other form of city-contextualized agriculture, also building based agriculture represent an
165 opportunity for urban food security, health, social inclusion, economic development and
166 environmental management (Van Veenhuizen, 2014), adding moreover specific contributions
167 related to the special location and tight connection with buildings. The main positive implications
168 of Urban Rooftop Farming may be grouped based on the three pillars of sustainability as reported
169 in the following Table 1.1 (Hui, 2011).

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171

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Table 1.1 Opportunities of URF (adapted from Hui, 2011)

<i>Environmental sustainability</i>	<i>Social sustainability</i>	<i>Economic Sustainability</i>
<ul style="list-style-type: none"> - Reduction of food transportation miles - Reduction of wastes generating less packaging - Mitigation of urban heat island - Increase of biodiversity - Decrease of air pollution - Urban storm water management - Sound insulation and noise absorption - Recycle of energy, organic wastes and water resources from the building - Reduction of pressure on land use and request 	<ul style="list-style-type: none"> - Active community participation - Green space and gardens for the community - Social inclusion - Education - Local employment - Amenity space for exercise and recreation - Aesthetic value - Increase of local food security 	<ul style="list-style-type: none"> - Increase of local food business - Sales of organic vegetable and food - Increase of property value - Improve of roof durability - Reduction of building cooling load and energy costs - Increase of roof life span - Increase of availability of biofuels

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The improvement of urban food security and nutrition is without any doubt a fundamental aspect of rooftop farming, especially in those developing countries where urbanization is spreading at the same pace of city dwellers economic gap, making nutritive food procurement increasingly difficult. As reported from researches held by the Food Agriculture Organization (FAO), rooftop farms can produce a significant amount of products within limited spaces thanks to the high efficiency in the use of the resources applied (Baudoin, 2017). Using innovative systems such as the “cubic garden” (FAO, 2016), it is now possible to gain cultivation space in volume, improving families capacities to self-produce healthful food and to balance their diets even in the lower strata of population. However, rooftop food production can be also expanded in wider and intensive systems and largely cover the daily requirements of an entire urban population, as estimated by a study in the city of London where the total roof space may provide 1.3 kg of crops per person per day (Dring, 2014). Accordingly, it was estimated that by transforming into vegetable gardens all flat roof surfaces of the city of Bologna, a production of more than 12’000 t year⁻¹ of fresh vegetables (covering more than 75% of the city requirements) could be achieved (Orsini, 2014). URF is also important for what concerns urban ecology. In fact, rooftop cultivation is a strategy to enhance flora and fauna biodiversity in cities context, creating green corridors that would help to reduce habitat fragmentation and to connect trophic webs for pollinators, predators and parasites (Bretzel, 2017). A case of study in the city of Vienna showed that linking green roofs with existing urban green spots, and depending on foraging distance of pollinators, it is possible to design a useful network to improve urban biodiversity and landscape (Dang, 2017). From a psychological point of view, redesigning urban landscape making it greener may also help to reduce stress and provide a pleasant escape from cities rhythm (Ulrich, 1986; Grahn and Stigsdotter, 2003).

198 Climate change is another environmental problem that greener cities can stem giving not only
199 adaptive, but also mitigation solutions (Georgiadis, 2017). Thanks to reflection of solar radiation
200 and plant evapotranspiration (Akbari, 2002; Ackerman, 2014), green roofs can act as cooling
201 systems against heat waves and heat island effect that typically affect urban microclimate. This
202 refrigerant action also concern interior building temperature and may help in energy costs
203 lowering, saving up to 15% of the annual energetic consumptions (Wong, 2003; Dunnett and
204 Kingsbury 2008; McIntyre and Snodgrass, 2010). Furthermore, rooftop cultivation can reduce
205 carbon footprint and therefore mitigate climate change, both shortening transportation food-
206 miles and reusing CO₂ building emission in integrated rooftop greenhouses (Sanyé-Mengual,
207 2017).

208 From a social standpoint, rooftop farming can strengthen community cohesion and address social
209 justice goals related to food security, health and local economic development. Nonetheless, to
210 ensure this form of justice, guaranteeing accessibility, social equity and integration is fundamental
211 and needs to start from attentive socio-political action. However, specific drawbacks of URF may
212 occur especially in case of prohibitive costs of maintenance and access to funding (Specht, 2017).
213 In addition, citizens' perception of rooftop farming may also represent a limitative aspect for its
214 social development, due to prejudices that still consider soil-less growing techniques "unnatural"
215 compared to traditional food production, as demonstrated by researches held in developed
216 European countries (Sanyé-Mengual, 2016; Specht, 2016).

217

218 **4. Design Elements of Rooftop Farms**

219 Rooftop farms can be integrated both in new and existing buildings. Nevertheless, newly built
220 constructions not only give architects and practitioners higher planning freedom, but also allow
221 anticipating structural and management problems, offering efficient solutions specifically designed
222 for the farming objective at lower prices. On the other hand, older building may lead to higher
223 costs of adaptation, minor rational use of rooftop surface and, in some cases, restricted range of
224 applicable cultivating techniques.

225 Despite the problems related to existing buildings, rooftop refitting still offers a wide number of
226 cultivation alternatives and represents the most common situation for rooftop farming cases
227 worldwide. Anyhow, it is fundamental to have a clear idea of the activities and crops to perform
228 since the first steps of the project, in order to understand structural loads and access problems
229 and therefore avoid future higher costs. In this initial phase, consultants' advices are also
230 important to guide farmers and entrepreneurs through the planning procedures and define the
231 amount of the investment (Caputo, 2017).

232 Both in existing and new buildings, there are essential design elements to take into account. These
233 elements are represented by roof structural load capacity; independent access to the farming
234 area; health and safety features for workers and visitors; and supply of farming resources (water
235 and energy) (Caputo, 2017).

236 Structural loads calculation needs to consider the cultivating substrate depth. According to the
237 German green roofs producer ZinCo Company, the recommended depth for intensive rooftop
238 farms is approximately 200 – 400 mm, depending on cultivated crops, with a weight of 300 kg m⁻²
239 for a medium saturated soil depth of 250 mm (Caputo, 2017). Although this depth allows the
240 cultivation of numerous plants including lettuce, onions, herbs, melons, cabbage and others, the

241 normal bearing capacity calculated for roofs is around 150 kg m^{-2} (Whittinghill, 2013; Castleton,
242 2010), and may vary depending on building age, use and regulations from belonging country. It is
243 possible to reduce roof load using special lightweight and free draining substrates, however water
244 tanks and winds load, especially in case of rooftop greenhouses, still require particular attention in
245 evaluations.

246 Access to rooftop is another fundamental aspect of design. If not independent, it may create
247 problems related to the privacy of residents or, in case of non-residential buildings, to the closing
248 time during night hours. When is not possible to arrange with building occupants for circulation
249 and rooftop use, it may be necessary to set up external stairs, trying not to impact on building
250 aesthetic and usability (Caputo, 2017).

251 Rooftop farms should also be respectful to those regulations that aim to ensure users safety and
252 health. Therefore, it is important to design capable railings, tall and screened enough to provide
253 not only an anti-fall barrier but also privacy for both farmers and neighbors (Caputo, 2017). Since
254 high roofs experience major wind speed effects compared to ground floor (Hanna, 2006), crops
255 need to be protected from wind damage (Oberndorfer, 2007) and structural components have to
256 be robustly connected to the building. In addition, air conditioning units have to be secured in
257 order to prevent dangers for rooftop users, remaining at the same time accessible for
258 maintenance (Caputo, 2017). As well, is important to integrate fire code regulations in rooftop
259 planning, foreseeing emergency exits and avoiding flammable materials use (Gorgolewski and
260 Straka, 2017).

261 Access to growing inputs such as water, energy or fertilizers can result as a limiting factor for
262 rooftop agriculture. Nevertheless, buildings produce resources that may be re-integrated in the
263 production cycle, creating a sustainable close system also conceptualized by scholars as a “rooftop
264 eco greenhouse” (Cerón -Palma, 2012). Accordingly, organic wastes, heat and greywaters
265 produced inside the building may be used in farming activity, reducing its emissions. In addition,
266 rainwater can be easily collected and then used for irrigation.

267 Designing a rooftop farm is also fundamental to consider planning codes provided by governments
268 and municipalities in relation to building safety and applicability. Since height limitations or
269 historical restrains may confine the practice to specific urban areas, is therefore important to start
270 from a right zoning of the farm. Choosing the building type is another important initial aspect,
271 which may compromise rooftop production in case of inappropriate structural systems
272 (Gorgolewski and Straka, 2017).

273 As mentioned before, rooftop farms can be designed with different degrees of technology
274 involved. In this direction, it is possible to distinguish three different categories of rooftop
275 agriculture: informal, formal and technological (Caputo, 2017).

276 The first category is characterized by low-tech systems, often self-realized with recycled materials
277 and restrained investment costs. The production is usually devoted to self-consumption and, in
278 most of the cases, practiced by raised beds such as timber containers that may reduce the initial
279 investment through the reuse of collected materials assembled by volunteers (Caputo et al.,
280 2017). The growing media commonly applied is agricultural soil mixed with compost and draining
281 substrates (e.g. perlite). It is fundamental to use lightweight substrates in order to minimize the
282 load applied on the roof (Rodríguez-Delfin, 2017). Simplified soil-less systems may also be applied
283 in low-tech farms due to their low weight and affordable installation. These systems are
284 specifically represented by simple hydroponic solutions such as the Nutrient Film Technique (NFT)

285 or floating systems, which can offer long-term benefits especially for low-income families
286 (Rodríguez-Delfin, 2017).
287 On the other side, formal rooftop farms use specific green roof technologies that requires major
288 investments as well as the consultation of experts and practitioners. Most of formal projects are
289 commercial or educational, and normally practiced on medium-large surfaces that can allow an
290 amount of production to cover expenses and guarantee a financial return (Caputo, 2017). The
291 building typologies preferred for these farms are usually non-residential, in order to exploit wider
292 spaces and have an easier access to roof. Collected rainwater as well as greywaters can be
293 integrated in the project to reduce irrigation costs. Solar panels can also be installed on green
294 roofs, with apparent higher output efficiency compared to those on gravel (Lamnatou and
295 Chemisana, 2015).
296 Finally, technological rooftop agriculture is the most developed farming system and employs
297 indoor innovations, high-tech hydroponic and aquaponic technologies installed in greenhouses or
298 dedicated indoor spaces. Compared to the previous typologies, it requires higher investments and,
299 for this reason, is especially applied by commercial enterprises that aim to achieve high profits and
300 can afford initial large costs (Caputo, 2017). Due to the high request of energy and resources,
301 these farms have a large footprint that make necessary the development of closed loop systems
302 interconnected to the building. As demonstrated by studies applied on ICTA-RTG experimental
303 rooftop greenhouse, the integration between building and greenhouse may be particularly
304 interesting in greenhouse climate regulation (Montero, 2016), where the greenhouse can act as a
305 solar collector and be used to heat the building below. As well, building heat can be exploited to
306 warm the greenhouse, enabling the production of winter crops without any external heating
307 source in a Mediterranean environment (Montero, 2017).
308

309 **5. Management of Rooftop Farms**

310 As any other agricultural system, even in the case of a rooftop farm is necessary to manage the
311 cultivation resources in the best conditions available. However, due to its peculiar location,
312 rooftop agriculture may encounter specific challenges related to growth inputs exploitation and
313 defense against biotic and abiotic factors. This section will discuss the main aspects of rooftop
314 farm managing with particular focus on water management and irrigation, nutrient supply,
315 sustainable pest control and safe and quality production.
316

317 **Water and Irrigation Management**

318 In the urban context, water use for farms irrigation competes with citizens' daily needs and
319 activities, pointing out the importance of a rational and efficient use of this resource. Water
320 management should use an interdisciplinary approach, in order to give a better perception of
321 transversal issues related to water exploitation (Dziegielewski, 2006). To achieve a globally
322 successful and sustainable water use, is fundamental to insist on water savings and citizens
323 behavioral change; source pollution reduction; irrigation systems improvement; adaptation and
324 resilience of climate change subjected areas; and promotion of information (Tsirogiannis, 2017).
325 From a rooftop farm point of view, a contribution to water conservation may be given through an
326 attentive planning and design, which takes into account not only technological aspects related to
327 components characteristics, but also operation practices such as irrigation scheduling, system

328 maintenance and performances monitoring. On rooftop conditions, also drainage systems acquire
329 an important role and may save infrastructures from water leak damages. In this direction, roof
330 slope and water routing must be tested before rooftop farm installation (Tsirogiannis, 2017), as
331 well as waterproofing system should be previously controlled by electronic detection systems
332 (Lockett, 2009; McIntyre and Snodgrass, 2010).

333 Rooftop agriculture may take advantage of alternative water sources, reducing or avoiding the use
334 of municipal tap water. Rainwater harvesting is a low impact practice that can be applied both in
335 simple or more complex systems. It is composed by a rainfall catchment, an irrigation system and,
336 eventually, a storage tank (Chang, 2011). Greywater also can be used as an alternative water
337 source, although it may contain contaminants, that may reduce its applicability. Legal limitations
338 on the use of greywater for irrigation are often found (Sanz and Gawlik, 2014), since it may
339 contains microorganisms, chemical compounds or physical agents that could put in risk both
340 human health and environment.

341

342 **Mineral Nutrition Management**

343 Rooftop agriculture is most of the times performed with a soil-less system (or hydroponic), as it
344 can lead to higher yield and quality of crops compared to those grown in standard soil (Olle, 2012).
345 Furthermore, it facilitates weeds and diseases control, ensuring a constant water supply and a
346 lower specific weight at the same time.

347 Although hydroponic systems can allow a higher and faster production, they have low buffering
348 capacity at roots level against pH, temperature and moisture changes, requiring therefore a
349 constant control (Pardossi, 2017). Nutrient content, pH and ion concentration in the solution need
350 also to be constantly checked and, in the case of closed loop systems, be adjusted depending on
351 previous uptake from the plants. Compared to open systems, closed systems are those
352 recommended for a sustainable growing, though disinfection treatments (UV light, heat, chemical
353 oxidation or micro-filtration; Postma, 2008) are needed in order to avoid root disease outbreak.

354 Mineral fertilizers are the most used in soil-less systems thanks to their high solubility and stability
355 of ionic forms, which determine an easier and faster absorption by plant roots (Pardossi, 2017).

356 However, also organic fertilizers can be applied for plant nutrition, despite their lower availability
357 that should be addressed by enriching the content of microorganisms in the growing media.

358 Numerous organic materials are available for organic soil-less culture, from animal manure to
359 municipal organic solid wastes, even though attention to eventual abiotic contaminants and
360 pathogens is always needed.

361

362 **Sustainable Pest Management**

363 Due to their location in urban context, rooftop farms should be run in pesticide-free conditions.

364 Although the use of chemicals in human proximity is regulated by specific codes, dangerous
365 effects may always occur and manifest especially on more susceptible subjects such as children
366 (Alarcon, 2005; Nasterlack, 2006). Accordingly, an organic integrated pest management is the best
367 option for rooftop agriculture, as it integrates biological, physical, mechanical and agronomical
368 methods to prevent pests and disease development and therefore avoid synthetics use.

369 A rooftop farm can be considered as a mini-agroecosystem, with ecological interactions and
370 biological communities that make it close to a greenhouse system, and with a geographical
371 isolation and population dynamics that compare it to an island (Bazzocchi and Maini, 2017). The

372 low complexity of this closed structure can determine an easier pest control, either using
373 mechanical and physical means (Baudoin, 2013) or handmade bio-pesticides (macerated or
374 decoction) (Stroll, 1996). From a climatic standpoint, an uncovered rooftop farm is similar to an
375 arid or semi-arid-zone, with wide daily and yearly temperature fluctuation and low relative
376 humidity (Bazzocchi and Maini, 2017). These extreme conditions can help in pathogens decrease,
377 especially in case of fungal attack. Also Gasteropoda and Nematodes should become less
378 dangerous in such environments, although the biological use of entomopathogenic nematodes
379 (Stuart, 2015) and fungi (Wraight, 2016) may be compromised for the same reasons.
380 Unlike agricultural environment, where weeds are considered the main pest, in rooftop context
381 insects represent the major danger (Racke and Leslie, 1993). Noxious insects can reach high floors
382 flying independently on the roof, being transported by wind or entering through infested farming
383 materials. Though the first two cases are impossible to control, in the latter one is possible to limit
384 contamination by an attentive farm design, creating separated zones where to leave eventually
385 contaminated clothes and tools from the outside. In the same way, plant and seeds need to be
386 examined before plantation and put in "quarantine" conditions at least for few days (Bazzocchi
387 and Maini, 2017). Insects monitoring is also fundamental to prevent infestations, using specific
388 detection systems or "indicator plants" (e.g. *Vicia faba* L., petunia) (Bazzocchi and Maini, 2017).
389 Weed management is normally easier on a roof than in an open field. Mechanical and physical
390 practices such as solarization or mulching can be applied to limit competitions. Also rotation is a
391 good limiting technique, though less effective in small and intensive systems on roofs. Concerning
392 plant disease management, due to extreme climatic conditions it should be a minor problem. Plant
393 resistance, beneficial microorganisms as well as good agronomical practices are useful tools to
394 limit fungal, bacterial or virus attack. Against insects, both biological and physical means can be
395 useful: mass trapping, beneficial insects, banker plants but also natural insecticides, represent
396 good sustainable solutions to protect the crops from infestations (Bazzocchi and Maini, 2017).

397

398 **Quality and Safe Production**

399 Rooftop products should follow the same quality and safety standards of field crops. However, due
400 to different growing conditions related to location, it may not be always possible to guarantee
401 equal requirements. Regarding the food quality on rooftop grown products, it may be affected by
402 shading of surrounding constructions, heat island effect, cars pollution, limited water, speed wind
403 and other factors (Alsanius, 2017). Quality is influenced by environmental factors such as light,
404 temperature, wind and precipitations that are normally amplified to extreme conditions on high
405 buildings, leading therefore to less nutritive and palatable products.

406 Product safety is however a fundamental aspect of food production regulated by legislation. In the
407 case of rooftop horticulture, legislators have to take into account the specific challenges of urban
408 cultivation, also considering the lack in knowledge of non-professional growers and amateurs that
409 most of the time conduct rooftop farms. Physical, biological and chemical hazards such as foreign
410 bodies, bacteria or heavy metals, may contaminate the products because of the limited skills of
411 the growers or by garden visitors. Routes of transmission are numerous and includes irrigation
412 water sources, growing media and organic or inorganic nutrients (Alsanius, 2017). Also, domestic
413 and wild animals could act as vectors of contamination, with particular reference to birds such as
414 pigeons, which represent a well-known problem for microbial contamination (Nielsen, 2006;
415 Heddem, 2006).

416 **6. Cases: Worldwide Experiences**

417 Rooftop agriculture is now spreading worldwide and gathering the interest of a growing number of
418 amateurs, entrepreneurs and policy makers. In the last decade, numerous cases emerged in every
419 continent, reflecting differences in farming characteristics resulting from the existing local
420 economies, population necessities and government or non-government agencies involved. While
421 some richer countries are already focusing on commercial high-tech systems to create proper
422 productive urban farms, the Global South of the world is mostly using rooftop farming as a tool to
423 promote food security and local development through the cooperation of local authorities and
424 NGOs.

425 Compared to other continents, North America has demonstrated the strongest interest for green
426 roofs exploitation, giving birth to numerous experiences both socially and commercially oriented.
427 Various cities in Canada and USA are now supporting rooftop farming as a mean to integrate local
428 food production, adapting urban codes to rooftop usability and access, and therefore helping to
429 improve the sector (De Zeeuw, 2017). One of the most famous experiences in North America is
430 *Gotham Greens*, a commercial enterprise that since 2011 has developed four rooftop
431 greenhouses, the latter of which is by the moment considered the biggest in the world with its
432 almost 7000 m² of cropped surface. The greenhouse uses advanced production technologies and
433 sustainable facilities to optimize crop performances, achieving a yearly yield around a half a
434 million kg of leafy greens and herbs (De Zeeuw, 2017).

435 In the same way, developed Asian countries such as Japan, China and Hong Kong, are investing in
436 this form of agriculture to address typical problems that concern large oriental metropolis such as
437 a lack of land for food production, growing interest in local safe vegetables and need of green
438 spaces for leisure and recreation. *Rooftop Republic at Fringe Club* in Hong Kong is an example,
439 offering workshops, educational tours and other leisure activities beside organic vegetable
440 cultivation on a rooftop surface of approximately 90 m² (De Zeeuw, 2017). Rooftop farming is also
441 spreading in the less developed part of Asia, especially in the form of small-scale raised beds
442 installed in private terraces or balconies, also known with the name of "*terrace gardens*". As in the
443 case of Bengaluru city, India, where workshop on terrace gardening have been offered through
444 local initiatives and NGOs to improve population nutrition, with positive feedbacks from interested
445 urban dwellers (De Zeeuw, 2017).

446 Although less advanced in comparison to North America and Asia, also in Europe it is possible to
447 find rooftop agriculture initiatives, which can vary from social gardens to research farms or
448 commercial activities with profit aim. Social experiences are more common in the southern part of
449 Europe, where open-air rooftop farms have been set up to promote social inclusion and
450 community empowerment, as represented by *Via Gandusio Garden* in Bologna, Italy (Sanyé-
451 Mengual, 2018). Research institutes, such as *RTG-Lab* in Barcelona, Spain, are also investing on the
452 sector, experimenting new farming technologies and improving building and rooftop greenhouses
453 interaction (Pons, 2015; Sanyé-Mengual, 2014; Sanyé-Mengual, 2015c). Commercial rooftop farms
454 are still rare to find, and the economic sustainability of the sector is being questioned as
455 *UrbanFarmers de Schilde*, with its 1200 m² of greenhouse and 400 m² of aquaculture system (often
456 considered the most innovative example of a European commercial farm (De Zeeuw, 2017)
457 experienced bankruptcy in early 2018.

458 Latin America especially offer small-scale rooftop farms created to face nutritional issues in low-
459 income families. Brazil, Peru, Colombia, are some of the countries where simplified hydroponic

460 systems were successfully applied, leading not only to an improvement of nutrition and health,
461 but also to a proper income source. In Lima, Peru, thanks to a ministerial project that aimed to
462 ameliorate economic situation and employment in urban areas, a group of women had the chance
463 to create a small business producing lettuce in simplified floating systems. For some women, the
464 selling income gave the chance to reinvest money and go on with the business after the end of the
465 project, also changing the floating system to a nutrient film technique (NFT systems) and therefore
466 implementing the production (De Zeeuw, 2017).
467 Similar cases of micro-farming in residential houses were also applied in Africa and Middle East, as
468 represented by initiatives held in Amman, Gaza or Cairo (De Zeeuw, 2017). These projects,
469 especially supported by international development organizations, gave good results but did not
470 lead to an expansion of the model. In some Sub-Saharan countries, awareness about rooftop
471 farming potentialities is still low, demonstrating the necessity of a major involvement of local
472 authorities. Also in Australia and New Zealand, local rulers are limiting rooftop agriculture
473 development, supporting green roofs for environmental purposes but not allowing productive
474 activities. Despite this restriction, the city of Melbourne, Australia, gives a virtuous example of
475 urban rooftop production, allowing the *Fed Square Pop-Up Patch* to use 1000 m² of a car park in
476 the Business District of the city to provide local residence and businesses with allotments where to
477 produce their own food (De Zeeuw, 2017).
478

479 **7. Summary and Future Trends**

480 Rooftop cultivation is an innovative building-based agricultural technique that may enrich urban
481 context with numerous benefits related to social, economic and environmental aspects,
482 addressing food security, health, social inclusion, urban poverty and climate change. It can be
483 practiced in the form of therapeutic farms, community gardens, image roofs for hotels and
484 restaurants, leisure gardens for employees, commercial enterprises, research and educational
485 centers, or private green terraces. The technologies applied can be more or less sophisticated and
486 especially differ depending on project budget and main purpose. Growing system choice can also
487 be influenced by infrastructure characteristics of the building, since load bearing capacity may
488 limit soil depth or impose the use of low-weight hydroponic systems.
489 Due to their peculiar location on buildings, rooftop farms have to be compliant with local urban
490 planning and building codes for what concerns safety and aesthetic aspects such as seismic
491 resistance, fire prevention, historical constraint or height limitation. This tight connection with the
492 building can also determine specific benefits such as building waste recycle (water, heat, CO₂ and
493 organic waste) or building climatic insulation, leading therefore to positive ecological
494 consequences on the urban carbon footprint.
495 Being a new practice, it still has to undergo rigorous research and improved, from both
496 technological and sustainability points of view. In particular, research should further focus on
497 connections between farming and building emissions, in order to improve building wastes
498 exploitation for cultivating activity and therefore achieving a sustainable food production and a
499 better urban living quality. Government authorities have to work on legislation in order to
500 overcome the actual limitations and help the future development of the sector. In the same way,
501 research need to be increased to ameliorate growing systems and therefore determine major
502 resource use efficiency and wastes recycle. Water management is another important aspect to

503 improve, trying to boost a sustainable use of rainwater and greywater instead of drinkable tap
504 water.
505 Despite current limitations, interest in rooftop farming is growing and positive feedbacks received
506 from currently active cases are giving good hopes for a future development. North America is
507 already demonstrating great sensitivity for this form of agriculture and other developed countries,
508 especially in Europe and Asia, are expected to follow the same trail in the next few years.
509

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