Future of Urban Farming series: Fertile-city

Discovering the potential of integrated rooftop greenhouses
Future of Urban Farming series: Next event

30 January 2020
Aquaculture Systems
Future of Urban Farming series: Stay up-to-date!

Social media: WUR Student Challenges
www.urbangreenhousechallenge.nl
Future of Urban Farming series: Fertilecity

An opportunity towards environmental sustainability in cities

November 6th 2019

Prof. Xavier Gabarrell (UAB)
FertileCity II Project

Integrated rooftop greenhouses: symbiosis of energy, water and CO2 emissions with the building – Towards urban food security in a circular economy

www.fertilecity.com
URBAG Integrated System Analysis of Urban Vegetation and Agriculture

A Horizon 2020 and European Research Council funded project, hosted by ICTA-UAB, to determine to what degree green infrastructures can be a source of sustainable food, reduce environmental impacts, and promote a more efficient use of resources in urban regions.

gara.villalba@uab.cat

November 2019- November 2024
Integrate life cycle modeling with atmospheric modeling

Atmospheric Modeling

- Pollutants
- Temperature
- Greenhouse gases

Life Cycle Modeling

- Resources: food, energy, water
- Impacts: GHG emissions, pollutant emissions, eutrophication, ...

URBAG
Greenhouses to Reduce CO₂ on roofs
An innovative and multidisciplinary approach to reduce CO2 in the building and agricultural sectors by combining energy exchange and local food production.
By implementing greenhouse on the rooftop of a building.

Rooftop greenhouses as **useful equipment** for:

- Reuse resources not consumed by the building \( \Rightarrow \) recovered heat-loss
- Collect \( \text{CO}_2 \) produced by people and building activities for the benefit of plants
- Increasing food resilience in urban areas
4 pilots: to experiment and demonstrate the reduction of energy emissions from roof greenhouses
FertileCity II. Integrated rooftop greenhouses: symbiosis of energy, water and CO$_2$ emissions with the building – Towards urban food security in a circular economy

CTM2016-75772-C3-1-3-R, (2017-2019)

Partners:

ICTA-UAB

Universitat Autònoma de Barcelona

UPC

Universitat Politècnica de Catalunya

Barcelonatech

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<table>
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<th>Entity</th>
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<td>UAB - ICTA</td>
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<td>Arq. Coque Claret</td>
<td>UPC</td>
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<td>Dr Elisa Lopez Capel</td>
<td>University Newcastle</td>
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<td>Water</td>
<td>Dr Daniel Barceló</td>
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<td>Dr Francesc Castells</td>
<td>Universitat Rovira i Vigili</td>
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<td>Dr Francesco Orsini</td>
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<td>Design</td>
<td>Dr Pere Llorach</td>
<td>Elisava</td>
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<td>2017</td>
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<tr>
<td>MSc Anna Petit-Boi (2017)</td>
<td>Maria Berlanga (IES, 2018)</td>
<td>Laura Sánchez Robles (IES La Romànica, 2019)</td>
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<td>Meritxell Gres Cintas (Biotec, 2017)</td>
<td>Fabiana Corcelli (U. Napoles, 2018)</td>
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<td>Anna Boneta (2018)</td>
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</table>
Materials & Methods

The Rooftop Greenhouse Lab (i-RTG-Lab) New building ICTA-ICP (UAB) May 2014 - Bellaterra, Barcelona 1st integrated RTG in Spain

Our case study

Our crop study
Any method of growing plants without the use of soil as a rooting medium, in which the inorganic nutrients absorbed by the roots are supplied via the irrigation water.
The Rooftop Greenhouse Lab (i-RTG-Lab)

New building ICTA-ICP (UAB)  
May 2014 - Bellaterra, Barcelona

1st integrated RTG in Spain
Quantified water flows:

- Rainwater supply
- Irrigation
- Potentially usable wastewater from RTG-Lab
- Wastewater from toilets and washing machines

**Surface: 500 m²**

**Eureka building**

**RAINWATER**

75% Surface: 1,600 m²

25%

**i-RTG-Lab**

**ICTA-ICP building**

35 m³

100 m³
i-RTG-LAB: Development of bean crop

In contrast to conventional RTG projects, the RTG-Lab is an Integrated RTG (i-RTG) that exchanges the residual flows (energy, water and gas) with the ICTA-ICP building. Different crops have been cultivated: tomato, lettuce... and bean.
Fertilecity II: Towards a bidirectional connection
**Building-Greenhouse Interconnection**

<table>
<thead>
<tr>
<th>Daytime</th>
<th>Conventional production</th>
<th>i-RTG-Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day</strong></td>
<td>Extreme temperatures for crop production (&gt;35ºC), particularly in summer</td>
<td>Building → <strong>Cold air</strong> → Greenhouse</td>
</tr>
<tr>
<td><strong>Night</strong></td>
<td>Extreme temperatures for crop production (&lt;15ºC), particularly in winter</td>
<td>Building → <strong>Waste heat</strong> → Greenhouse</td>
</tr>
<tr>
<td><strong>Day</strong></td>
<td>CO₂ is injected to supply crop demand to enhance photosynthesis and crop yield</td>
<td>Building → <strong>CO₂</strong> → Greenhouse</td>
</tr>
</tbody>
</table>

Also... natural ventilation of the greenhouse!
3.1 Objectives

To grow common bean in an i-RTG to assess the suitability of the system for growing this type of crop and to detect any possible problem during the growing period in the autumn season and in a Mediterranean climatic area.

- To analyze the impacts of common bean production in hydroponic i-RTGs using the life cycle assessment methodology
- To find the hotspots derived from the production of common beans in hydroponic i-RTGs, and propose potential environmental improvements for future crops
- To assess the suitability of producing locally-grown food by studying the economic framework of the area
CROP ANALYSIS AND CHARACTERIZATION

<table>
<thead>
<tr>
<th>Periodic methods</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis</td>
<td>Freq.</td>
</tr>
<tr>
<td>pH</td>
<td>diary</td>
</tr>
<tr>
<td>Ce</td>
<td>diary</td>
</tr>
<tr>
<td>Fertilizers - leachates</td>
<td>3 per week</td>
</tr>
<tr>
<td>Water entrance</td>
<td>diary</td>
</tr>
<tr>
<td>Ion Chromatography</td>
<td>Flowmeters</td>
</tr>
</tbody>
</table>

**Other analysis**
- Substrate (Perlite)
- Residual biomass (leaves, stem and roots)
- Bean (fruit)

**Other materials**
- Atomic Spectroscopy
- Temperature and HR sensors

Follow-up by agronomic experts

Life cycle assessment

- Goal and scope
  - Goal and scope definition
- Inventory
  - Inputs and outputs data compilation
- Impact assessment
  - Classification
  - Characterization

**Functional Unit**
1 kg of edible beans produced in the ICTA-ICP i-RTG

ISO 14040-44 (ISO 2006a, 2006b)
Economic-commercial framework analysis during the harvesting period

To notice if there is a necessity of beans supply in the local market by gathering the origin of fresh product and analyzing yearly price fluctuations.
LCI

System boundaries

i-RTG INFRASTRUCTURE
- GREENHOUSE STRUCTURE
- RAINWATER HARVESTING SYSTEM
  - Water pump
  - Water tank
- AUXILIARY EQUIPMENT
  - Pumps, digital timer, flow meter
  - Water tanks
  - Pipes, valves, joints, drippers
  - Others

OPERATION
- INPUTS
  - FERTILIZERS
  - SUBSTRATE
  - WATER
  - ENERGY
  - OTHERS
- OUTPUTS
  - LOCAL FOOD PRODUCTION
  - WASTE
    - WASTEWATER (LEACHATES)
    - SUBSTRATE
    - BEAN BIOMASS
  - RESIDUAL HEAT (FROM BUILDING)

LIFE CYCLE STAGES
- MATERIALS
- PROCESSING
- TRANSPORT
- CONSTRUCTION
- MAINTENANCE
- END OF LIFE

LIFE CYCLE STAGES
- MATERIALS
- PRODUCTION
- TRANSPORT
- USE
- END OF LIFE
## IMPACT ASSESSMENT (PER FU)

<table>
<thead>
<tr>
<th>Category</th>
<th>Aux. Equipment</th>
<th>i-RTG</th>
<th>RW-HS</th>
<th>Substrate</th>
<th>Water</th>
<th>Energy</th>
<th>Nur. plants</th>
<th>Nutrients</th>
<th>Pesticides</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change</td>
<td>3.37</td>
<td>30.21</td>
<td>54.77</td>
<td>1.63</td>
<td>0.92</td>
<td>2.51</td>
<td>1.32</td>
<td>5.03</td>
<td>0.23</td>
<td>5.67E+00</td>
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<tr>
<td>Terres. Acidification</td>
<td>2.93</td>
<td>29.03</td>
<td>48.75</td>
<td>1.94</td>
<td>1.00</td>
<td>5.74</td>
<td>1.16</td>
<td>8.88</td>
<td>0.58</td>
<td>2.04E-02</td>
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<tr>
<td>Freshwater Eutroph.</td>
<td>1.21</td>
<td>35.06</td>
<td>33.27</td>
<td>0.64</td>
<td>4.07</td>
<td>5.89</td>
<td>1.43</td>
<td>17.81</td>
<td>0.63</td>
<td>9.43E-04</td>
</tr>
<tr>
<td>Marine Eutroph.</td>
<td>0.30</td>
<td>4.15</td>
<td>44.06</td>
<td>0.27</td>
<td>0.14</td>
<td>0.36</td>
<td>0.56</td>
<td>49.88</td>
<td>0.28</td>
<td>8.75E-03</td>
</tr>
<tr>
<td>Fossil Depletion</td>
<td>5.90</td>
<td>23.34</td>
<td>60.17</td>
<td>2.81</td>
<td>0.72</td>
<td>2.20</td>
<td>1.43</td>
<td>3.17</td>
<td>0.28</td>
<td>2.02E+00</td>
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<tr>
<td>Ecotoxicity</td>
<td>1.53</td>
<td>19.91</td>
<td>49.14</td>
<td>0.54</td>
<td>1.95</td>
<td>2.06</td>
<td>8.69</td>
<td>15.74</td>
<td>0.44</td>
<td>9.39E-02</td>
</tr>
</tbody>
</table>

- **Rainwater Harvesting System**: +IMPACTING in 4/6 categories (Max: 60.2% in FDP)
  - Mainly due to **Glass Fiber Reinforced Plastic** (100 m³ water tank material)

- **I-RTG infrastructure**: most impacting in Freshwater Eutrophication (35.1%)

- **Fertilizers**: most impacting in Marine Eutrophication (49.9%)

- Less impacting category: **Pesticides**, with <1% of impact in all categories analysed
Bean production. Autumn 2016

- Plantation: September 13th
- 1st harvest: October 20th
- Last harvest: November 8th
- 57 days of plantation (20 days of harvest)
- PRODUCTION: 43.81 kg (*0.5 kg·m⁻²)
- Commercial production: 88%
- Non-commercial production: 12%

*distance between perlite sacks was adjusted for previous tomato crops, with higher space requirements

However... all EDIBLE production was considered to perform the LCA, due to the crop small area!

Production beneficiaries are the same building inhabitants!
General results

Economic-commercial framework

Price and quantity of beans at market level in Mercabarna (2016)

During ICTA-ICP crop harvesting period:
- Highest Price!
- Low quantity of beans available at market level!

OFF-SEASON PRODUCTION
i-RTGs like ICTA-ICP’s could provide fresh, locally-grown vegetables to the market when there is more necessity of these products!
Agronomic feasibility of producing bean crop in i-RTG

Temperature

Relative Humidity
AVG 66.74%

PRODUCTION
43.81 kg
0.5 kg·m⁻²

Use of rainwater represented 55% of tap water saving

However...

Rainwater Harvesting System is the most impacting item in the Impact Assessment

- i-RTG infrastructure
- Fertilizers (Nutrients)
- Substrate, Energy
- Auxiliary Equipment, Water, Nursery plants, Pesticides

Economic feasibility of producing bean crop in i-RTG

Locally-grown beans when the yearly-price is higher and the supply amount is lower
3.2: Crop Calendar

**Figure**. Crop calendar:

T – Tomato;
L – Lettuce;
G – Green oak lettuce;
R – Red oak lettuce;
M – Maravilla lettuce;
B – Green bean;
S – Spinach;
C – Chard;
R – Arugula;
P – green pepper.
Goal & Scope

Unidades funcionales y límites del sistema

<table>
<thead>
<tr>
<th>Infraestructura</th>
<th>Operación</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse structure¹</td>
<td>Fertilizers (+ emissions to water)</td>
</tr>
<tr>
<td>Rainwater Harvesting System (RWHS)² Or tap water</td>
<td>Substrate</td>
</tr>
<tr>
<td>Auxiliary Equipment**</td>
<td></td>
</tr>
</tbody>
</table>

FU1: 1 kg de producto fresco  
FU2: 1 € de valor al mercado al por mayor

Figure 2. System boundaries of the System for Intercrop environmental assessment. Simple scheme

Cálculo de impactos

• Software: SimaPro 8.5
• Background data: Ecoinvent v3
• Approach: cut-off

• Method: ReCiPe Midpoint (H)¹
• Impact categories²,³:
  • Climate Change (CC) – kg CO2 eq.
  • Terrestrial Acidification (TA) – kg SO2 eq.
  • Freshwater Eutrophication (FE) – kg P eq.
  • Marine Eutrophication (ME) – kg N eq.
  • Fossil Depletion (FDP) - kg oil eq.
  • Ecotoxicity (ET) = Σ Marine (MET), Terrestrial (TET) and Freshwater (FET) toxicity – kg 1,4-DB eq

Results & Discussion: Yield

Figure 4. Yields of the different crop cycles. T – Tomato; L – Lettuce; G – Green oak lettuce; R – Red oak lettuce; M – Maravilla lettuce; B – Green bean; S – Spinach; C – Chard; R – Arugula; P - green pepper.
Results & Discussion: LCIA

CC impact per Kg of Yield

0.44 ± 0.05 Kg CO2 eq / Kg

0.49 – open air (Kulak et al., 2013)
0.54 – polytunnel (Kulak et al., 2013)
3.79 – UK (Audsley et al., 2010)
1.30 – Europe (Audsley et al., 2010)
0.51 – greenhouse (Khoshnevisan et al., 2014)
0.72 – High-Tech indoor (Cellura et al., 2012)
3.45 – Denmark (Møller Nielsen, 2007)
1.30 – Sweden (Halberg et al., 2006)

Figure 5. CC impact per kg of yield. T – Tomato; L – Lettuce; G – Green oak lettuce; R – Red oak lettuce; M – Maravilla lettuce; B – Green bean; S – Spinach; C – Chard; R – Arugula; P – green pepper.
Impacto relativo en CC

Figure 6. Impactos relativos de cada cultivo en Cambio Climático. T – Tomate; L – Lechuga; G – Lechuga hoja de roble verde; R – Lechuga hoja de roble roja; M – Lechuga “Maravilla”; B – Judía verde; S – Espinacas; C – Acelgas; R – Rúcula; P - Pimiento verde.
Which is the most efficient year-round combination of crops that have less environmental impact in a Rooftop Greenhouse?
Yearly Scenarios

• Based lowest-impacting crops
  • Yield functional unit
  • Economic value functional unit

• “Vacation periods”
### Results & Discussion: Scenarios

<table>
<thead>
<tr>
<th>Crop Cycles</th>
<th>Month</th>
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<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>N01</td>
<td></td>
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<td>N02</td>
<td></td>
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<tr>
<td>T3</td>
<td></td>
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<tr>
<td>T2</td>
<td></td>
</tr>
<tr>
<td>N2</td>
<td></td>
</tr>
<tr>
<td>T5</td>
<td></td>
</tr>
<tr>
<td>T5</td>
<td></td>
</tr>
<tr>
<td>N1</td>
<td></td>
</tr>
<tr>
<td>N3</td>
<td></td>
</tr>
<tr>
<td>L4,L5</td>
<td></td>
</tr>
<tr>
<td>L5,L6</td>
<td></td>
</tr>
<tr>
<td>N4</td>
<td></td>
</tr>
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</table>

**Scenario 0**
- 945.43 kg CO₂ eq./year
- 0.65 kg CO₂ eq./kg
- 0.84 kg CO₂ eq./€

**Scenario 1**
- 982.19 kg CO₂ eq./year
- 0.50 kg CO₂ eq./kg
- 0.88 kg CO₂ eq./€

**Scenario 2**
- 907.56 kg CO₂ eq./year
- 0.59 kg CO₂ eq./kg
- 0.78 kg CO₂ eq./€

**Scenario 3**
- 902.08 kg CO₂ eq./year
- 0.59 kg CO₂ eq./kg
- 0.75 kg CO₂ eq./€

**Scenario 4**
- 904.69 kg CO₂ eq./year
- 0.59 kg CO₂ eq./kg
- 0.71 kg CO₂ eq./€
...and the remaining impact categories?

- Studies focus on single crops (mainly tomato)
- Low comparability between studies!
- Studies focus on single impact categories (mainly CC/GWP)
- High diversity of impact assessment methods (CML, ReCiPe, etc.)
Future of Urban Farming series

Thank you!