VERTICAL

The re-development of vacant urban structures into viable food production centres utilising agricultural production techniques
PROBLEM STATEMENT

2 PROBLEMS, 1 POSSIBLE SOLUTION
NL, 2014: 8,000,000 M² VACANT

SOURCE: VASTGOEDMARKT.NL
CITIES RELY ON THEIR AGRICULTURAL HINTERLAND FOR FOOD SUPPLY

CITY EXPANSION EXPELS AREA FOR FOOD PRODUCTION

THE ‘GROWING’ CITY - BUILDING INTEGRATED AGRICULTURE

REDEVELOPMENT OF EXISTING URBAN STRUCTURES INTO FOOD PRODUCTION CENTRES
CONCEPT

STRUCTURAL VACANCY + CONTROLLED ENVIRONMENT AGRICULTURE = FOOD SUPPLY FOR THE CITY GROWN IN THE CITY

PROBLEM + TECHNOLOGY = OPPORTUNITY
OUTLINE OF THE RESEARCH
HOW IS THIS RESEARCH CONDUCTED?
HOW CAN AGRICULTURAL PRODUCTION TECHNIQUES BE ADAPTED IN THE RE-DEVELOPMENT OF VACANT BUILDING STRUCTURES, IN ORDER TO MINIMISE THE ENERGY EXPENDITURE PER UNIT OF PRODUCE?
DESIGN METHODOLOGY
MATRIX OF POSSIBILITIES

PRODUCTION
TECHNIQUES

STRUCTURE

ENERGY

LOCATION INPUT: Hong Kong

LOCATION INPUT: Netherlands

DESIGN CASE STUDY

PERFORMANCE ASSESSMENT

DESIGN CASE STUDY

PERFORMANCE ASSESSMENT

CONCLUSIONS &
RECOMMENDATIONS FOR FUTURE RESEARCH
OUTCOME MEASURES

- PRODUCTION CAPACITY
  - Production area \([m^2]\)
- ENERGY USE
  - Total energy usage \([kWh]\)
- PRODUCTION OUTPUT
  - Total production \([kg]\)
LITERATURE STUDY

DESIGN INPUT
PRODUCTION TECHNIQUES
HYDROPONIC PRODUCTION

DEEP FLOW TECHNIQUE (DFT)

NUTRIENT FILM TECHNIQUE (NFT)

EBB AND FLOW TECHNIQUE (EFT)

AEROPONICS
DEEP FLOW TECHNIQUE

SPACE FLEXIBILITY

WATER EFFICIENCY

ENERGY EFFICIENCY

HARVEST MANAGEABILITY

ROOT ENTANGLEMENT
NUTRIENT FILM TECHNIQUE

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HARVEST MANAGEABILITY

ROOT ENTANGLEMENT
Concrete elements
- Masonry (load-bearing)
- Glazing (curtain-wall)
- Closed elements (curtain-wall)

n/a
- Curtain
- Overcladding
- RC tile cladding
- Precast concrete
PAR SPECTRUM
400 - 700 nm

SPECTRAL IRRADIANCE W/m²nm

WAVELENGTH nm

WAVELENGTH nm
THE MAXIMAL PHOTOSYNTHETIC EFFICIENCY IS DEPENDENT ON THE BALANCE OF PPF AND CO₂

A SINGLE FACTOR CAN LIMIT THE TOTAL PRODUCTION EFFICIENCY
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root Temperature</td>
<td>24 °C</td>
</tr>
<tr>
<td>Aerial Temperature</td>
<td>24 → 31 °C</td>
</tr>
<tr>
<td>Photosynthetic Active Radiation</td>
<td>500 µmol/m²s</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>50 - 95%</td>
</tr>
<tr>
<td>Carbon Dioxide Concentration</td>
<td>1000 PPM</td>
</tr>
</tbody>
</table>
\[ Q_R + Q_F + Q_V + Q_S + Q_P + Q_L + Q_H = 0 \]
\[ Q_R + Q_{Facade} + Q_{Plant} + Q_L + Q_{Equip} + Q_{HVAC} = 0 \]

\[ Q_{Facade} + Q_{Plant} + Q_L + Q_{Equip} + Q_{HVAC} = 0 \]
AMBIENT AIR \((\chi_a, T_a)\)

\[ R_{net} \]

- AERODYNAMIC BOUNDARY LAYER RESISTANCE

\[ r_a \]

SURFACE (STOMATAL) LAYER RESISTANCE

\[ r_s \]

LEAF TISSUE \((\chi_a, T_a)\)
**ENERGETIC FLUXES**

**SINGLE PRODUCTION LAYER - ILLUMINATED**

- **232 W RADIATION LED**
- **109 W HEAT LED PRODUCTION**
- **123 W RADIATION PPF**
  - **36 W REFLECTED RADIATION**
  - **87 W ABSORBED RADIATION**
  - **87 W PHOTOMORPHOGENESIS**
  - **10.22 W SENSIBLE HEAT**
  - **76.78 W LATENT HEAT**

- **~54.5 W RADIATIVE HEAT TRANSFER**
- **~54.5 W CONVECTIVE HEAT TRANSFER**

- **54.5 W RADIATION**
- **54.5 W CONVECTION**
- **36 W REFLECTED RADIATION**
- **0 W PHOTOMORPHOGENESIS (NEGLIGIBLE)**
- **10.2 W SENSIBLE HEAT**
- **76.8 W LATENT HEAT**

**SINGLE PRODUCTION LAYER - NON-ILLUMINATED**

- **15.83 W SENSIBLE HEAT**
- **15.8 W SENSIBLE HEAT**
- **-15.8 W LATENT HEAT**
- **-15.8 W LATENT HEAT**
DESIGN METHODOLOGY
CEA FACILITY

SEEDING & HARVESTING OF CROPS
- Seeds for germination
- Germination and transplant of seeds
- Provide plant support structure
- Monitor & report plant maturity
- Facilitate harvest of produce

PLANT HEALTH
- Limit penetration of pathogens
- Monitor & report plant health

NUTRIENT DELIVERY
- Facilitate central supply of nutrients and water
- Balanced mixing of nutrients and water
- Control nutrient solution temperature
- Aeration of nutrient solution
- Determine nutrient solution conditions

AERIAL ENVIRONMENT
- Determine and monitor air conditions
- Carbon dioxide enrichment
- Control air composition
- Control air temperature
- Control relative humidity
- Determine subsequent lighting conditions

PPF
- Control PPF spectrality
- Control PPF intensity
- Control PPF duration and timing

EQUIPMENT SUPPORT
- Provide structural support
- Provide adequate radiation protection

Legend:
- Plant production system
- Air management system
- Nutrient delivery system
- Superstructure
- Lighting system
- Data handling system
RE-DEVELOPMENT METHODOLOGY

- Selection of existing vacant urban structure for redevelopment
- Analysis of present construction typology and grid dimensions
- Subdivision of total structure into subsequent modules
RE-DEVELOPMENT METHODOLOGY
FAÇADE TYPOLOGIES

TYPE A - THE THERMOS

TYPE B - THE GREENHOUSE

TYPE C - THE DOUBLE SKIN

TYPE D - THE SOLAR GUIDE

TYPE E - THE PARTITION
TYPE E
CASE STUDIES

IMPLEMENTATION OF CEA IN STRUCTURE
DESIGN CASE STUDIES

TWO LOCATIONS

HONG KONG SAR

THE NETHERLANDS
STEP 4
STEP 5
RESULTS
FAÇADE TYPOLOGIES

- OPAQUE INSULATED
- TRANSPARENT INSULATED
- TRANSPARENT INSULATED
- OPAQUE NON-INSULATED
- TRANSPARENT NON-INSULATED
- TRANSPARENT NON-INSULATED
SEPARATE TIMED, STATIC INTERNAL LOADS
SINGLE, CONTINUOUS FACADE MATERIAL
NATURAL VENTILATION EXCLUDED
441 M² PRODUCTION PER LAYER
SIMULATED BODY OF WATER (24°C)
ADIABATIC CEILING

ABSTRACTION OF MODEL
COOLING LOAD COMPARISON

MODEL 1 - TRANSPARENT INSULATED

MODEL 1 - TRANSPARENT NON-INSULATED

MODEL 1 - OPAQUE INSULATED

MODEL 1 - OPAQUE NON-INSULATED
BEST PERFORMANCE

OPAQUE & NON-INSULATED

TOTAL COOLING LOAD [kWh] | -1,041,997
---|---
RELATIVE COOLING [kWh/m²] | 118

TOTAL ENERGY USE [kWh] | 3,474,115
---|---
RELATIVE ENERGY [kWh/m²] | 1,969
ABSTRACTION OF MODEL

A. SEPARATE TIMED, STATIC INTERNAL LOADS
B. SINGLE, CONTINUOUS TRANSPARENT FACADE
C. OPAQUE FACADE SEGMENT - PROJECT WALL
D. INSULATED DOUBLE MIRROR PARTITION
E. 231 M2 PRODUCTION TOTAL
F. 383 M2 PRODUCTION PER LAYER
G. ADIABATIC CEILINGS

NL - SPLIT
COOLING LOAD COMPARISON

MODEL 2 - TRANSPARENT NON-INSULATED - ZONE 1

MODEL 2 - TRANSPARENT NON-INSULATED - ZONE 2

MODEL 2 - TRANSPARENT INSULATED - ZONE 1

MODEL 2 - TRANSPARENT INSULATED - ZONE 2
## Final Comparison

**Split-Zone Production, Non-Insulated**

<table>
<thead>
<tr>
<th></th>
<th>Output Area [m²]</th>
<th>Relative Cooling [kWh/m²]</th>
<th>Relative Energy [kWh/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1764</td>
<td>118</td>
<td>1,969</td>
</tr>
<tr>
<td></td>
<td>1763</td>
<td>142</td>
<td>1,906</td>
</tr>
</tbody>
</table>

![Diagram showing the comparison](attachment:image.png)
ABSTRACTION OF MODEL

A. SEPARATE TIMED, STATIC INTERNAL LOADS
B. SINGLE, CONTINUOUS FACADE MATERIAL
C. NATURAL VENTILATION EXCLUDED
D. 1185 M2 PRODUCTION PER LAYER
E. SIMULATED BODY OF WATER (24°C)
F. ADIABATIC CEILING
COOLING LOAD COMPARISON

MODEL 1 - TRANSPARENT NON-INSULATED

MODEL 1 - TRANSPARENT INSULATED

MODEL 1 - OPAQUE NON-INSULATED

MODEL 1 - OPAQUE INSULATED

Sensible cooling load (kWh)  Total cooling load (kWh)
ABSTRACTION OF MODEL

A. SEPARATE TIMED, STATIC INTERNAL LOADS

B. SINGLE, CONTINUOUS TRANSPARENT FACADE

C. OPAQUE FACADE SEGMENT - PROJECT WALL

D. INSULATED DOUBLE MIRROR PARTITION

E. 381 M2 PRODUCTION TOTAL

F. 1185 M2 PRODUCTION PER LAYER

G. ADIABATIC CEILINGS
### FINAL COMPARISON
SPLIT-ZONE PRODUCTION, NON-INSULATED

<table>
<thead>
<tr>
<th></th>
<th>OUTPUT AREA [m²]</th>
<th>RELATIVE COOLING [kWh/m²]</th>
<th>RELATIVE ENERGY [kWh/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>4,740</td>
<td>132</td>
<td>1,985</td>
</tr>
<tr>
<td>Right</td>
<td>3,525</td>
<td>146</td>
<td>1,929</td>
</tr>
</tbody>
</table>
GENERAL DISCUSSION

A BROADER PERSPECTIVE
DISCUSSION
THE TORENHOVE, DELFT

- Climate control
- Production
- Climate control
- Production
- Germination & seeding
- Food processing
- Retail
- Nutrient delivery
- Waste management

| FOOTPRINT [m²] | 902 |
| OUTPUT AREA [m²] | 29,917 |
| FRESH PRODUCTION [kg] | 1,437,000 |
| RELATIVE ENERGY [kWh/m²] | 1,906 |
| TOTAL ENERGY [GWh] | 57 |
### DISCUSSION

**CENTRAL PLAZA, HONG KONG**

<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOOTPRINT [m²]</td>
<td>2,180</td>
</tr>
<tr>
<td>OUTPUT AREA [m²]</td>
<td>222,075</td>
</tr>
<tr>
<td>FRESH PRODUCTION [kg]</td>
<td>10,654,000</td>
</tr>
<tr>
<td>RELATIVE ENERGY [kWh/m²]</td>
<td>1,929</td>
</tr>
<tr>
<td>TOTAL ENERGY [GWh]</td>
<td>428</td>
</tr>
</tbody>
</table>
- Footprint of Central Plaza: 2,180 m²
- Total production area (CEA): 222,075 m²
- Traditional open field agriculture: ~5,200,000 m²
CONCEPT

STRUCTURAL VACANCY

CONTROLLED ENVIRONMENT AGRICULTURE

FOOD SUPPLY FOR THE CITY GROWN IN THE CITY

PROBLEM + TECHNOLOGY = OPPORTUNITY
RECOMMENDATIONS

FINANCIAL VIABILITY

POSITION IN LOCAL AND GLOBAL FOOD NETWORKS

CLOSED LOOP DESIGN

IMPROVE COOLING AND DEHUMIDIFICATION TECHNIQUES

ENERGY STORAGE

CROP SELECTION

SOFTWARE SELECTION FOR CLIMATE SIMULATION