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Short communication

Vertical farming: Skyscraper sustainability?

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ABSTRACT

It is predicted that the world population will reach 9 billion by 2050, of which 70% will live in urban centres. This change, alongside a changing climate, will strain Earth's resources, especially the food supply chain. One idea that has been proposed to address this issue is vertical farming – the urban farming of fruits, vegetables, and grains, inside a building in a city or urban centre, in which floors are designed to accommodate certain crops. While an interesting theoretical concept, no studies currently exist that quantify or qualify the validity of such an idea. The purpose of this paper, therefore, is to examine the feasibility and plausibility of the vertical farming concept from a socio technical, mixed methods, research perspective. This includes (1) examining how much energy is needed to power such a building and whether renewable energy can meet the onsite demands of the building by constructing a energy model, (2) quantifying the carbon footprint of vertically grown produce and subsequently comparing that to conventionally grown produce, and (3) conducting interviews to explore how relevant stakeholders perceive the concept of vertical farming in order to identify what are current barriers and opportunities exist towards possible uptake of the technology. The findings indicate that vertical farming is a tool that can be used to supply food to cities in a sustainable manner, but this depends on the location and design. Areas of future research are identified.

1. Introduction

It is predicted that the world population will reach 9 billion by 2050, of which 70% will live in urban centres (United Nations, 2007). This change, alongside a changing climate, will strain Earth's resources, specifically the food supply chain. Food supply and security is a growing area of concern, and a topic worth evaluating is how produce can be supplied to cities in a way that is environmentally friendly and energy efficient (Godfray et al., 2010). A valuable investigation would be to determine alternative methods to supply food to cities alongside current agricultural practices in a sustainable manner.

One idea is the concept of vertical farming. Vertical farming is the urban farming of fruits, vegetables, and grains, inside a building in a city or urban centre, in which floors are designed to accommodate certain crops using hydroponics (water with nutrients) (Fischetti, 2008). While the concept of supplying food in cities is not a new one, the idea of dedicating an entire building/skyscraper to cultivate produce is. The concept of vertical farming is a large scale extension of urban agriculture *within* a building (Despommier, 2009).Novel contributions have been published on vertical farming. Besthorn (2013) has examined the history of urban agriculture and reviewed the promise that vertical farming holds for communities with food security problems. Kurasek (2009) has provided some architectural designs of how the concept may be developed. Sivamani, Bae, and Cho (2013) have examined the viability of smart technology in agriculture and the promise that it may hold for vertical farming.

While much has been published on the subject of urban agriculture and more recently on the conceptual potential of vertical farming, limited evidence has been published on the viability of vertical farming. No technical analyses on vertical farming have been found to date. The purpose of this research, therefore, is to investigate the feasibility and plausibility of the vertical farming concept from a socio-technical, mixed methods, research perspective in three specific and interrelated research domains.

These three research domains are: (a) to examine how much energy is needed to power such a building and whether renewable energy can meet the onsite demands of the building by developing a simplified energy model, (b) to determine the carbon footprint of vertically grown produce and subsequently compare that to produce grown conventionally, and (c) to investigate how relevant stakeholders perceive the concept of vertical farming in order to identify what are current barriers and opportunities exist towards

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possible uptake of the technology. In the rest of this paper, the (1) methods, (2) results, (3) discussion, and (4) conclusion will be presented.

2. Methods

First, the literature was surveyed in order to select a design to model. Due to the novelty of the field, as well as the small number of relevant publications, there were a limited number of designs to select from – but the ones that were found were comprehensive in nature (designs found in Despommier (2009) and Fischetti (2008) were considered). After surveying the literature, it was decided that Dr. Dickson Despommier's design was the most appropriate to be used as a basis for this research. This decision was based not only on the fact that Dr. Despommier is credited with developing the concept of vertical farming, but also because his research provided the most thorough and realistic design when compared to the other sources that were surveyed. An image of the design can be found in Despommeir's Scientific American publication (Despommier, 2009). In the design, light is used to cultivate the crops inside the building and water is pumped throughout the building for the hydroponic culture. Solar panels are placed on the roof and on the facade (one side). Therefore, using this design as a basis, the energy flows (demand and generation) were quantified.

The purpose of quantifying the energy flows was to specifically determine how much energy is needed to power such a building (demand) and whether renewable energy can meet the onsite demands of the building (generation). For the energy demand, the amount of energy required to light the building and pump the water was calculated. Lighting and water pumping are two of the main energy demand items, and was therefore the focus of this research. For energy generation, the amount of energy generated from solar panels was quantified. Favourable assumptions were made in order to see if this design is possible in a best case scenario. The timeline for the energy flows was over the course of a month.

In order to examine the energy flows, an energy optimization model was developed. The reason that an optimization model was developed was because the amount of energy required to power the building is contingent on the building dimensions. When a building occupies a larger area, the lighting and water requirements increase, but so does the amount of energy available (via solar panels on the roof and facade). The opposite is also true – the lighting and water requirements in the building decrease when the building occupies a smaller area, but so does the amount of energy available (less number of solar panels available on roof and facade). Therefore, different dimensions were examined in the model in order to ascertain the feasibility and plausibility of vertical farming. Assumptions made in each of the three components (lighting, water pumping, solar panel energy generation) for the model will be described next.

Lighting is a requirement in vertical farming at the scale that Despommier (2009) calls for in his design. Lighting options are either LED (light emitting diode) or HPS (high pressure sodium). HPS lights will be used for this study[1]. 600 W lamps will be assumed, and this finding was confirmed in various sources (Blacquiere & Spaargaren, 2003; Spaargaren, Hortilux Schreder, & P.L. Light Systems Inc.).

According to the literature, the amount of lighting needed indoors for plant cultivation is around 18 h per day (Blacquiere & Spaargaren, 2003). Light shelves were used to optimize the amount of light going in (therefore minimizing the amount of light that needed to be generated), and the height of each window was maximized to 3.5 m (height of each floor).

For the water requirements, hydraulic energy equations, the Moody Diagram, pumping equations, and head loss equations were used to calculate the amount of energy needed to pump the water in the building. An estimate was sought in order to calculate the amount of water required for hydroponic farming – which was found to be one litre per square foot per day (or 10.7 l per square metre) (Resh, 2004). An energy calculation was made for each floor in order to determine how much energy was required to pump the water for each specific floor, and then the values were summed up for the total amount of energy needed to pump through the entire building. Minor losses were ignored. Standard assumptions were made regarding pipe size and pipe material.

For the solar panel energy generation, the calculation was based in an area with lots of solar radiation (Phoenix, Arizona) and very efficient photovoltaics (240 W). The Suntech solar panel has monocrystalline silicon solar cells and the dimensions are 1956 mm × 992 mm × 50 mm, which was used for this research (Suntech, 2007).

Based on the dimensions inputted, the optimization model calculated the amount of energy required to light and pump the building (based on the floor area assumed for each iteration). A solar panel calculator (BD calculator) was used to determine the number of solar panels needed to meet the energy requirements (from lighting and water pumping calculations) (2010).

The model then explored whether the building could accommodate the number of PVs required based on the roof area/facade available due to the dimensions assumed. The height was kept the same (30 floors, 105 m in total height) in order to see if vertical farming was feasible in high rise buildings.

The limitation of this approach was that only one building design was investigated (Despommier, 2009). It is important to highlight that different conclusions could have been reached with different designs (different energy generation/demand assumptions), but again, the most practical and realistic design out of all available designs that were surveyed was selected (Despommier, 2009).

Secondly, a limited life cycle analysis of produce grown vertically was quantified. A pilot vertical farming programme in the UK was found, which provided an opportunity to collect data on the carbon footprint of vertically grown produce. At the pilot, data was available for vertically grown lettuce, and therefore was the produce that was quantified for the scope of this study (kg CO_2/kg lettuce). No other crops had data available at the pilot.

Data was collected from the pilot and the technology provider. Estimates were developed based on data collected with the pilot and technology provider through a site visit and a data collection interview. Plant propagation, fertilization, irrigation, harvesting, and heating/lighting were identified as the major energy outputs, and were therefore quantified based on the data collected.

From this, the carbon footprint of vertically grown lettuce was calculated – and this was compared to lettuce grown conventionally in the summer and the winter time in the UK (Hospido et al., 2009). The same carbon conversions that were used in Hospido et al.'s study were used in this research. However, there were two areas that were not included in the carbon footprinting because data was not available. First, the lettuce is grown for two weeks at a separate nursery (before it arrived at the pilot). Estimates were given for the energy inputs required to harvest/grow the lettuce for the first two weeks, but the estimates/numbers could not be reconfirmed and were therefore omitted. Secondly, a literature review was conducted to estimate the amount of carbon associated with developing hydroponic nutrient culture. However, no tangible studies were found. These limitations are identified.

[1] LED lights were not used in this study because after corresponding with organization that sells the vertical farming technology, it was found that while energy can be saved because of the increased efficiency of LEDs, a higher number of lights are needed for cultivation because of the lower light intensity range. This assumption was therefore used in this research.