From local to global: engaging in the world's food challenges through a mushroom cultivation case study.

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I would like to thank my supervisor Dr Marie Davidová for her amazing support and professional and academic guidance throughout the journey to create this dissertation and also Dr Yangang Xi my initial supervisor for grounding the research technically. Other staff members of the Welsh School of Architecture will be in my debt for their technical and emotional support during difficult times over the last two years. Also thank you to my family and friends who have put up with me as I became a student once again in a new century!

Yr wyf i Cynan Jones yn cadarnhau fod y wybodaeth yn y traethawd hir hwn yn waith gwreiddiol gennyf i. Pan fydd gwybodaeth o ffynnonellau eraill yn cael eu defnyddio, cadarnhaf fod hyn wedi ei nodi.

I, Cynan Jones hereby confirm that the work in this dissertation is my own. Where information has been derived from other sources, I confirm that this has been indicated.

Abstract

The interdisciplinary approach to explore the potential for designing an energy efficient mushroom growing environment that can be linked to living spaces, is invaluable for innovative future indoor agricultural technologies to address food security issues in a way that fits with sustainable food production within Circular and Foundational economies. The author has developed a concept for high-quality, high-volume edible mushroom cultivation (mainly Shiitake and Oyster mushrooms) within a built space that can be established at relatively low cost in urban settings. The concept has been developed by the author from the growing system of *The Mushroom Garden,* Snowdonia which was originally designed as a diversification and new income generating model for farmers.

The conceptualised model works as a functional full-scale prototype in Snowdonia that has been replicated in other situations and this dissertation focuses on three diverse Case Studies that show the flexibility of the concept: firstly the commercial business of *The Mushroom Garden,* Snowdonia, Wales, secondly the *Carbon Zero Battlesfield Hotel* in Northumberland, England and thirdly *Awen Cymru*, a social enterprise in Bridgend, Wales. The dissertation discusses themes which are central to the development of integration in both urban built areas and rural areas and each theme is discussed individually with main points noted below:

- **Sustainable production of clean, healthy, and nutritional food** - Following initial set up costs (in the region of £6,000), the running costs are minimal. Recent research work by the author has discovered ways of making the system more energy efficient. All aspects of the growing process ensure that the food is healthy and nutritious.

- **Food security** - the system allows control over the production of the mushrooms from substrate production to harvesting, all within a relatively small built area and can be applied to situations of extreme weather or conflict as well as long term food production for isolated rural communities or post-industrial urban areas.
- **The Circular economy** - substrate for growing the mushrooms is produced locally e.g. park or roadside wood chip in cities for Shiitake mushrooms and any organic waste for Oyster mushrooms e.g. straw, grass cuttings, used coffee or used hops and barley from breweries. In fact, any organic waste can be used to produce Oyster mushrooms. When the mushrooms have been harvested the growing substrate can be mulched or composted by gardeners and growers.
- **The Foundational economy** - The foundational economy is built from the activities which provide the essential goods and services for everyday life, regardless of the social status of consumers. These include, for example, infrastructures; utilities; food processing; retailing and distribution; and health, education, and welfare. In essence, it is an economic model based on a community's needs and assets (human and built) rather than the traditional model of wants fuelled by mass consumption.

The matter of food security is increasingly becoming the focus of attention by many national and international governments and organisations as well as national and global NGO's. The challenges that food security presents to many poorer and rural communities have implications further than for the communities themselves. The dissertation reviews the case study of the health and nutritional benefits of Shiitake and Oyster mushrooms and looks at the yields and nutritional values of the mushrooms (including Vit D) under various light regimes (fluorescent and LED) and the costs incurred. The energy inputs into the growing system are analysed and recommendations for increased energy efficiency of the growing system are discussed. The dissertation concludes that the concept and the circular techno-environmental and social system can produce high quality nutritious food with minimal investment in a variety of Post-Anthropocene environments and demonstrates a transition to a bio-digital edible landscape.

The system may also yield valuable nutrients and other compounds from the runoff water and spent substrate which can contribute to a circular growing system when incorporated into other communal growing projects. There is also a potential to investigate the co-design of living and food growing areas i.e., edible households using The Mushroom Garden growing system and other techniques e.g., hydroponics, permaculture, and mini herbs gardens.

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1 INTRODUCTION TO THE MAIN THEMES

This is a non-reductionist, rich dissertation. Non reductionism is an approach in many spheres of research from architecture to life and political sciences. The concept is explored by Paul Jones (who argues that architecture should be guided by a broad political-economic context and not merely bureaucratically codified state regulations. The role of architecture, therefore, is to provide a cultural and social frame for economic development. This is classic non-reductionism as the complex approach involves several aspects which cannot be simplified into reduced elements. The approach depends on the interaction between the multiple elements, Jones argues, so that the architecture is embedded in the socio political and economic environment (Jones,Paul 2009)

Adopting the same approach this research does not focus on one element or issue, rather it examines several issues and their complex relationship with one another. Complexity arises in the two main matters under consideration, firstly the cultivation of Shiitake and Wood Oyster mushrooms and secondly the application of the growing system in various settings and their importance in contributing to and fitting into new economic models and aspects of food security. The cultivation involves a fine balance of environmental control within an insulated growing regime, and it is the balance of light, temperature, humidity, and air quality that creates the environment needed consistently to cultivate the maximum volumes and optimum nutritional benefits. It is a bio-technological approach to food production.

The Mushroom Garden Growing system, in its application, involves complex interactions with economic systems of food production, low environmental impacts and addresses the geopolitical issues raised by our globalisation and commoditising of food production, distribution and consumption. It comprises a unique model for “communitising” food production which is different from free market models as well as state sponsored models.

By contrast, reductionism has its roots in philosophy where ideas and concepts and even thought processes and beliefs are seen made up of singular elements which mean that all processes can be “reduced “to their constituent parts. This philosophy has been applied to other disciplines including science, technology, architecture, and medicine. Non-reductionism does not accept that all phenomena can be reduced to their constituent parts; rather some phenomena are a product of inter-reactions and co-operating elements creating a whole that is not merely the sum of its parts. This concept has been developed in a recent publication Entangled Life (Sheldrake, 2020) specifically with regard to fungi and their relationship and interdependence on interactions with other life forms such as bacteria, plants, algae and even humans. It is fascinating that work done by Sheldrake on the microscopic level with fungi can be replicated on a global, geopolitical level through The Mushroom Garden Growing system.

This introduction describes the aims of the project and the background to exotic mushroom cultivation, specifically Shiitake mushrooms (*Lentinula Edodes*) and Oyster mushrooms (*Pleurotus ostreatus*). Their nutritional and health choice properties. In essence this work is “research by design” done through full scale prototyping and a model for the research is produced below (see Figure 5). Research by design is an approach which adheres a design approach to practical activities and outcomes (Roggema, 2016). The approach is especially valuable in designing for the future in a rapidly changing environment, changing conditions and shifting policies and programmes. Therefore, there is constant need to implement feedback loops to gauge how developments affect the design process. There may be multiple loops to consider complex interactions, as described above, in relation to The Mushroom Garden growing system. The approach also allows for interactions with other developments in the same environment, e.g., the mushroom growing system integrating with other urban farms or growing projects.

Growing environments (such as lighting, temperature, and humidity) have significant effects on the quantity and quality of edible mushroom production. Detailed characteristics of each growing environment and optimum balance of energy consumption and high-quality produces all need to be identified. Moreover, it is expected that each of these factors may require differing configurations, therefore combinations of different growing environments will be investigated to understand the ultimate optimal growing environment in a scalable manner.

Firstly, this project aims to investigate the role of two technical innovations, namely LED lighting and high humidity, in achieving good quality edible mushroom production. Utilising integrated heat and mass transfer models and a continuum environment monitoring toolkit, which is available at the Welsh School of Architecture, several growing scenarios are tested, and the optimal solution will be identified. Edible mushroom growing techniques and facilities are provided by *The Mushroom Garden*, Snowdonia. The growing facilities allow accurate control of the growing environment, such as LED lighting density and spectrum, indoor temperature, and humidity.

Making food growing systems more energy efficient is becoming a global research topic. Nicole Rogers, in her blog on the 'Sustainable America' web site (Rogers, 2012), suggests five steps that can increase energy efficient food production, and how these steps are reflected in the Mushroom Garden System is identified below.

Farm to Fork Is Highly Inefficient; cultivation of food therefore needs to take place nearer to where it is consumed. The Mushroom Garden System is designed to provide local communities with locally grown nourishing food.

Exploit the Waste - The waste products from food production should be used for further food production if possible. The substrate used to cultivate mushrooms in the Mushroom Garden System is excellent mulch and compost for vegetable production.

Buy Local - Buying locally will not only reduce food miles but also help to keep the £ locally. The Mushroom Garden System is designed to produce more than a family could use so that income can be generated by selling locally.

More Crop per Drop -this is about getting the best quality and yield from the substrate and irrigation. The Mushroom Garden System requires very little irrigation and is very efficient in terms of energy input - however this research has demonstrated how energy efficiency can be further enhanced.

Better Behaviour- waste less produce. Increased efficiency requires consumers to waste less food. One of the aims of the Mushroom Garden System, especially in a community-based social enterprise, is to educate the community about food production and consumption and food waste is an integral part of this education.

Secondly, the project shows how the system can be replicated in many urban as well as rural areas in order that communities can control the cultivation and supply of high-quality food in a sustainable way and therefore increase the food security of those communities. There is also an opportunity to develop small income generating enterprises using the system.

Thirdly it is demonstrated how this system fits perfectly with both the Circular and Foundational economies and the suitability of The Mushroom Garden System to designing spaces for living and sustainable food cultivation is explored.

Fourthly and finally, how the mushroom cultivation system can be applied to the Post-Anthropocene era and its food security is examined.

The current global Covid -19 pandemic has brought into sharp focus the need for a global re-examination of agro-economics, production, distribution, and consumption of food. We have seen how long and convoluted our food chains are and how susceptible they are to severe disruption by a global emergency that pays no attention to cultures, economies, or borders. It has also highlighted how consumer behaviour, conditioned by many years of a perceived need for instant availability of a wide range of products with all year-round availability, can rapidly descend into chaos which exacerbates the situation evidenced, for example, by panic buying of food and hygiene products. In a recent article Cappelli & Cini discuss the disruption to food chains caused by the Covid-19 pandemic and suggest the answer would be to shorten the food chains so that production and consumption are both as local as possible. Such arrangements can be an effective lifeline to communities exposed to food shortages, be they rural or urban. It is also argued that quality of life within communities will improve as the micro-economies create employment opportunities and circulate money locally (Cappelli & Cini, 2020). This dissertation examines and describes a small-scale energy efficient food production model which addresses the concerns noted above. It also offers some practical steps to address these challenges. The fully developed commercial prototype is described as well as the production process, highlighting recent research into the energy efficiency of it. The discussion is framed around five issues of global significance; - **Sustainable Food Production**, issues of **Food Security** and the concepts of **Circular** and **Foundational Economies** and the increasingly important concept of the world in the **Post**-**Anthropocene era** which are discussed below**,** with definitions cited from a number of sources.

These issues are of global importance as has been highlighted by several reports, and research papers by several national and global organisations. To summarise, the challenges facing feeding the world's population cannot be addressed in isolation from several other global issues e.g., economic inequalities, political upheaval, conflict, environmental changes and natural disasters and pandemics. There needs to be a holistic approach involving new economic systems such as Circular and Foundational Economies, in parallel with sustainable food production and distribution systems. This dissertation shows how The Mushroom Garden cultivation system can provide a local, community-based answer to these global challenges.

1.1 SUSTAINABLE FOOD PRODUCTION

There are many definitions of what constitutes a sustainable food system. However, they all share common threads relating to local issues such as security, efficiency of production, and the health and wellbeing of consumers. Central to the concept of sustainable food production is that it is built on principles pertaining to the ecological, social, and economic values of a community and region (see Figure 1). Pothukuchi and Kaufman (Kaufman, Jerome; Pothukuchi, 2000),[(1] in their definition, place greater emphasis on efficiency of production and use of energy and processes that are in tune with local ecological and environmental conditions and the recyclability of waste. They also note that sustainability should consider the balance between food imports into the community and local capacity. This mirrors the principles of the Foundational Economy discussed below i.e., that production within a community should be driven by the needs of a community and not by the pressures of external corporations' view of what the community *wants.* In the case of the system described in this dissertation, the sustainability elements are the basis of the processes. This involves the fact that the growing substrate (wood chip) comes from sustainable sources such as managed woodlands and production requires sustainable low energy and labour input.

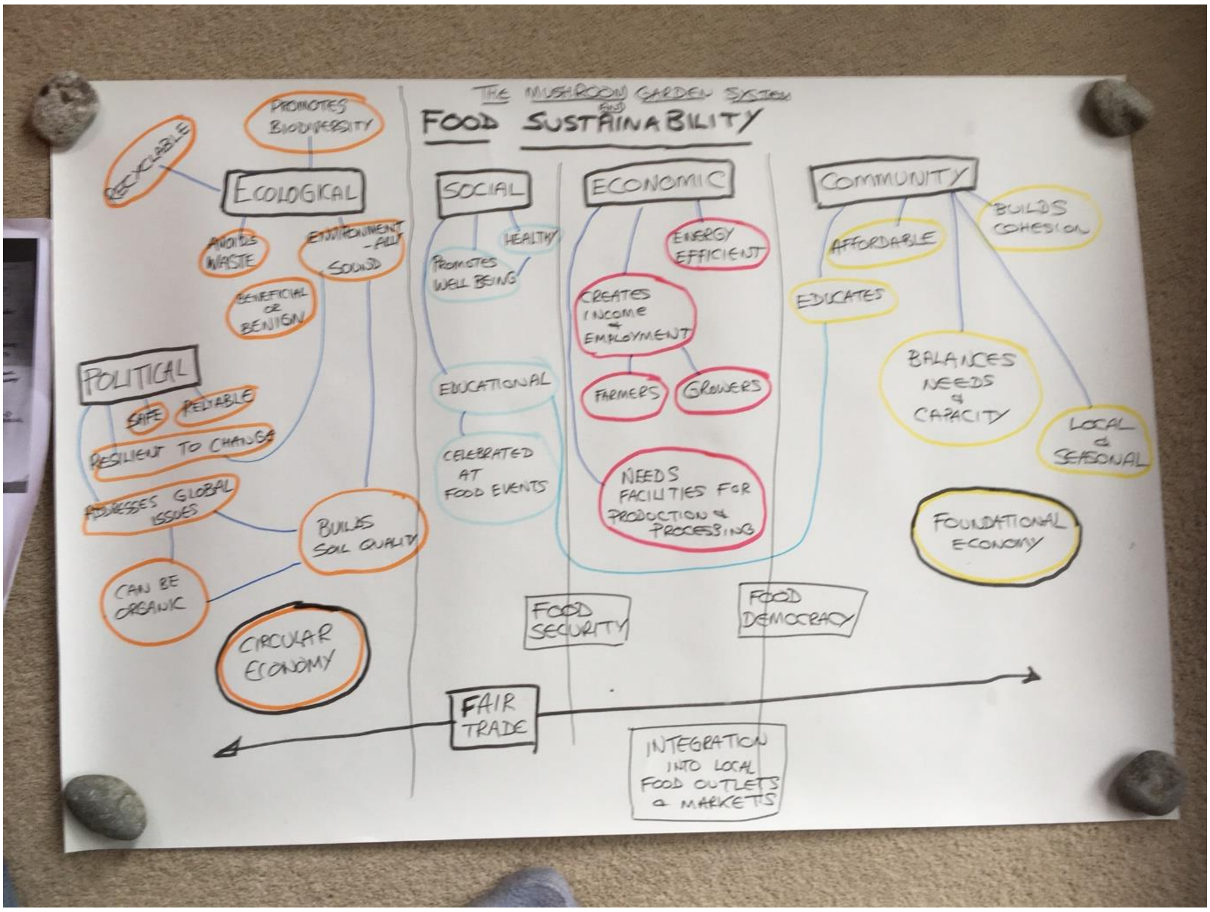

Figure 1: Diagram of Food Sustainability (Jones, 2020)

The Covid -19 pandemic has brought the issue of sustainable food production into sharp focus and the challenges have been addressed on the web site of the UK based charity Practical Action (Chettleborough, 2020) specifically challenging distribution and transportation issues. The charity argues that the food production and distribution system was broken before the pandemic and that the UK, and the world should not return to previous practices but adopt a new normal which is more sustainable. The Mushroom Garden system would address these challenges by localising food production and consumption.

1.2 Food Security

Food security is a measure of the availability of food and individuals' ability to access it. Affordability is only one factor. The issues of supply and demand also have a role to play as do local and global geopolitical situations and environmental changes. Food security incorporates a measure of resilience to future disruption or unavailability of critical food supply due to various risk factors including droughts, shipping disruptions, fuel shortages, economic instability, and wars. In an increasingly unstable world (from the global to the local) small scale solutions can help to inform large scale challenges. Producing food as close as possible to where it is consumed builds resilience and reduces the chances of disruption and interruption of supply. It maintains control over the food chain within the community.

Several elements contribute to food insecurity on a global scale (see **Error! Reference source not found.** and 2). These elements are food production and supply, energy requirements and water availability and quality. Producing food efficiently and locally helps to address these matters. In the recent publication *Food Bigger than the Plate* (Flood & Rosenthal Sloan, 2019) the editors discuss the disconnect between farming – that is the way we use resources and labour to create food - and urban life. In essence, the rural has become the location of food production and the urban its consumption. The projects covered by the publication's accompanying exhibition speculate on ways to reverse this trend and to integrate food production with urban living, utilizing small areas be they privately owned or communal.

Food Security is one of the current 17 actions to change the world published by the United Nations (United Nations, 2019). The report links food security challenges to poor nutrition, population and demographic shifts, wars and natural disasters which all contribute to global food insecurity. A recent virtual Conference hosted by the United Nations' Sustainable Development Platform (United Nations, n.d.). The conference focussed on transforming global food systems for affordable and healthy diets. It includes a powerful analysis of the cost saving of healthy diets due to "hidden costs" of bad nutrition and climate change. The conference formulated policy recommendations to transform world food systems.

The UN Development Programme (UNDP) has a mission to eradicate global poverty. A recent publication (United Nations, 2020) highlights the need for a holistic approach to achieve the aim of eradicating poverty with food production, distribution and security being central to the approach. One issue that contribute to food insecurity is addressed in this publication i.e., climate change leading to the formation of dust bowls in parts of Africa that used to be fertile and plagues of locusts in the Middle East that can devastate crops in a matter of hours. The following quotation sums up the content of the publication:

> *"UNDP doesn't tackle climate change or food security as stand-alone issues. Our approach improves productivity, profitability and sustainability from farm to fork."*(United Nations, 2020)

The UK government recognise that food security is a global challenge however a 2020 publication (Finlay, 2020) recognises that there is also food security challenges in some of the poorer communities of all the UK nations. The report describes the food insecurities in terms of access to affordable and nutritious food within several cohorts and demographics in the UK population, and identifies certain poorer and older communities more susceptible to food insecurities. The report notes that opposition parties and farmers' organisations are very critical of the 20120 Agriculture Act (UK Government, 2020) as it does not address the se insecurities. In addition to the points made above, food security involves a complex range of interconnected issues for example:

Politics on a global scale. The wealth gap between developed and developing countries can be a major source of conflict as governments compete for resources. The conflicts between states and increasingly within countries leads to the creation of refugees fleeing wars and persecution. This leads to increased pressure on the production and supply of food with food chains being broken.

Employment. Localising food production creates local employment opportunities and reduces the need for family bread winners to have to move away to find employment.

Communitisation of food production can help to avoid exploitation of workforces to produce cash crops for wealthy countries (e.g., flowers or biofuel) rather than food.

The Mushroom Garden Growing System discussed in this dissertation seems to be ideally suited to achieve this aim.

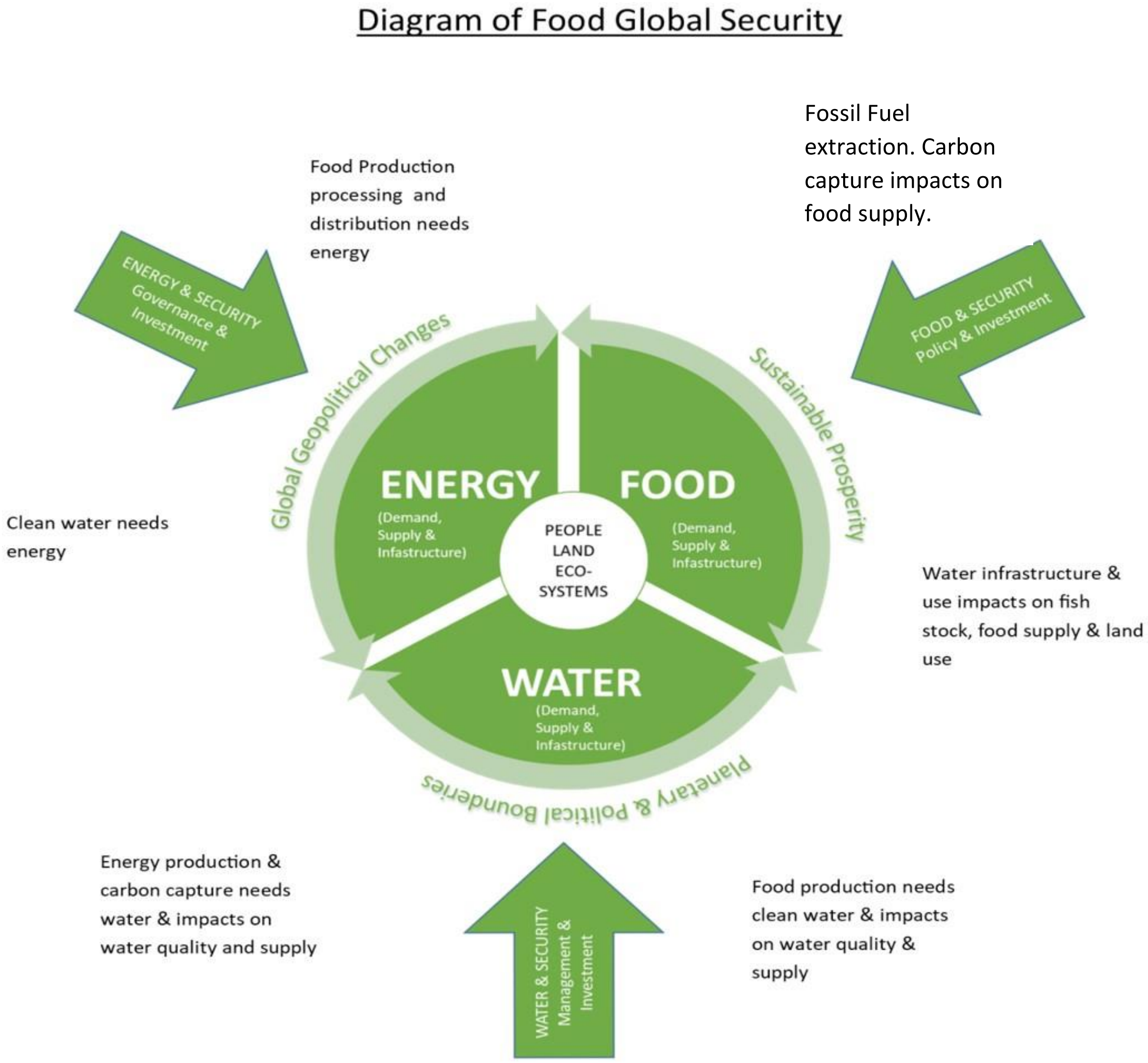

Figure 2: Diagram of Food Security redrawn by Jones 2020 based on Haddfield-Dodds (Haddfield-Dodds, 2015)

1.3 THE CIRCULAR ECONOMY

A circular economy is an alternative to a traditional linear economy consisting of manufacture, use/consumption, and disposal, Instead, it is an economy in which resources are kept in use for as long as possible, extracting the maximum value from them whilst in use, then products and materials are recovered and regenerated at the end of each service life. The Ellen McArthur Foundation in its publication, 'Cities and the Circular Economy for food;' (Ellen McArthur Foundation, 2019) describes three elements which contributes to the circular economy for food in an urban situation all of which are elements of the Mushroom Garden growing system and products. How this system bears with concurrence with the Foundation's indicative elements and summarized as follows:

‘**Source food grown regeneratively and locally where appropriate**’. - The growing substrate for the mushrooms can be sourced locally or at best regionally and is the waste product of tree surgery for Shiitake mushrooms and waste organic matter such as straw or sawdust for Wood Oyster production, and when used it is returned to the land or garden as mulch or compost.

‘Design and market healthier food products’ - The mushrooms grown in the system have a proven provenance for nutrition and taste.

‘**Make the most of food**’. - The system and the produce very little waste, all of which can be composted.’

The diagram below illustrates the Circular Economy of the Mushroom Garden System (see Figure 3).

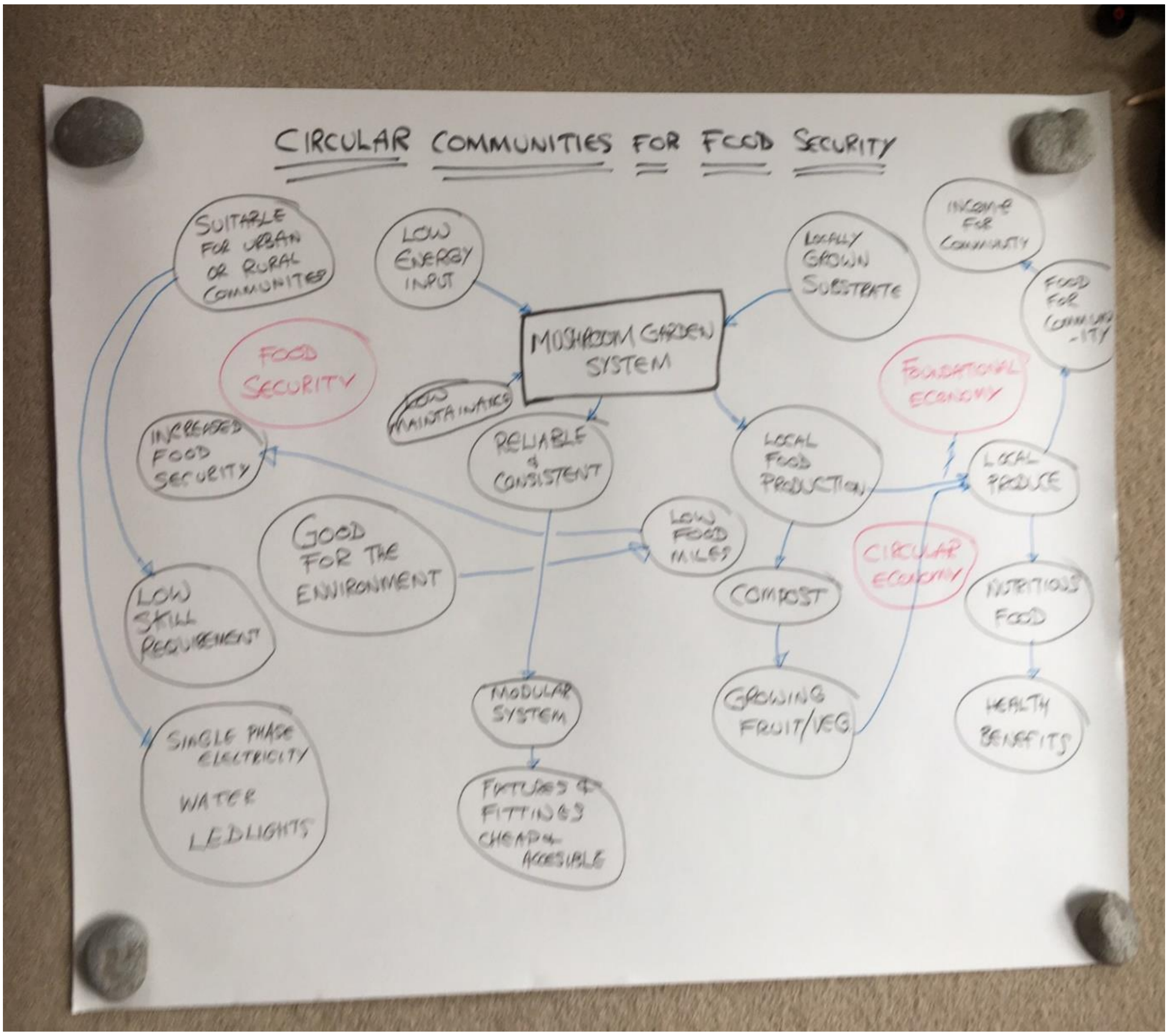

Figure 3: Diagram of Circular Economy (Jones, 2020)

The concept of the Circular Economy is not new but has seen a surge of academic interest in the last decade as a development evolving from the sustainability agenda. Another driver was the increase in environmental and waste reduction legislation mainly in China and the European Union. Geissdoerfe et al (Geissdoerfer, Savaget, M.P. Bocken, & Hultink., 2017) conducted a literature review of academic papers on the circular economy and sustainability and described the differences and similarities between the two concepts. Although the main body of the research is a study in how two related, but different concepts relate to each other, what is interesting is that the research shows how the Circular Economy concept has grown globally and is gaining momentum with policy makers nationally and globally. The reuse of waste from one process, (tree surgery) to cultivate mushrooms makes the Mushroom Garden approach a perfect fit with the Circular Economy.

1.4 THE FOUNDATIONAL ECONOMY

The Foundational Economy is a classic "bottom up" model. As opposed to the" top down" approach of many government institutions on local, regional, and national levels, it is a community-led economic model based on a community's real needs and rights. It does not blindly follow the perceived needs as laid out by dogmatic policies or the market, (see Figure 4). Bentham *et al.* take a broader view on the matter in the Centre for Research on Social and Cultural Change publication, 'Manifesto for the Foundational Economy'. They identify three major players that pose a challenge to the Foundational Economy namely the state, privatised utilities and supermarkets (Bentham *et al*., 2013). They demonstrate, however, how food production, distribution, and consumption, although overwhelming components of people's lives, can be addressed through the Foundational Economy. The Mushroom Garden's growing system is developed with the immediate needs of the community as the primary consideration, but, as the Mushroom Garden system is a Wales-based project, it is nevertheless a perfect fit for this important message from the Welsh Government, which has accommodated community consideration despite being an instrument of state.

The driving force behind the Foundational Economy is a collective of European academic researchers working together to develop a new way of thinking which challenges mainstream ideas about what economic policy should be. The collective published "The Foundational Economy" (Arcidiacono et al., 2018). This publication describes the basic philosophy behind the concept of the foundational economy and the content is succinctly expressed by a reviewer (Wolfgang Streek) as a compelling counter project against neo-liberalism, restoring the collective foundations of everyday life. The Mushroom Garden system in its community application has collective action and needs as a cornerstone. The community can get involved in all aspects of growing mushrooms from making substrate to growing and harvesting. In addition, community members can arrange for sales and delivery of the mushrooms locally. The spent substrate can be composted by community members for use in other community growing projects.

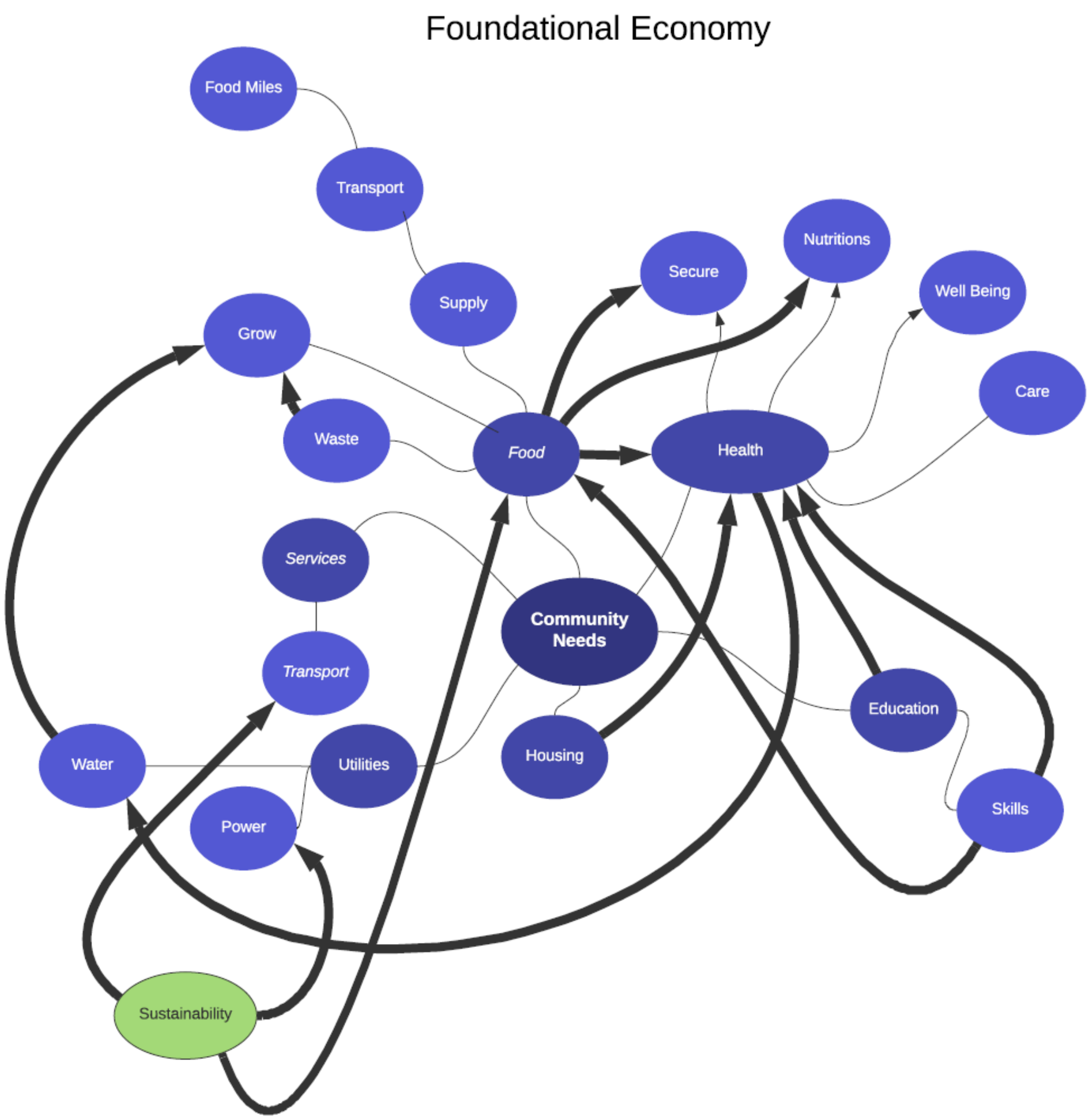

Figure 4: Diagram of the Foundational Economy (Jones, 2020)

1.5 POST-ANTHROPOCENE

Post-Anthropocene is a new concept in the field of human interaction with the planet. It is not a recognized geological epoch. However, it is a useful tool to map the future of humanity. The current geological epoch is termed the Holocene and has lasted approximately 10,700 yrs. This is the epoch that saw the development of humankind as we know it. Scientists have described the last few hundred years since the beginning of the industrial revolution, however, as the Anthropocene which signifies the period when humankind has had profound effects on the planet and societies. This is the first time that humans have influenced and changed the natural processes of the planet. Most commentators believe that the current situation in which the planet finds itself is not sustainable and various models have been created to visualize the next phase of human development on Earth (see Chapter 3 for a representation of the possible futures). The most beneficial future for meaningful human existence is described as the Post-Anthropocene and it represents a world where the planetary excesses of the past 300 years are reversed.

1.6 Research by Design

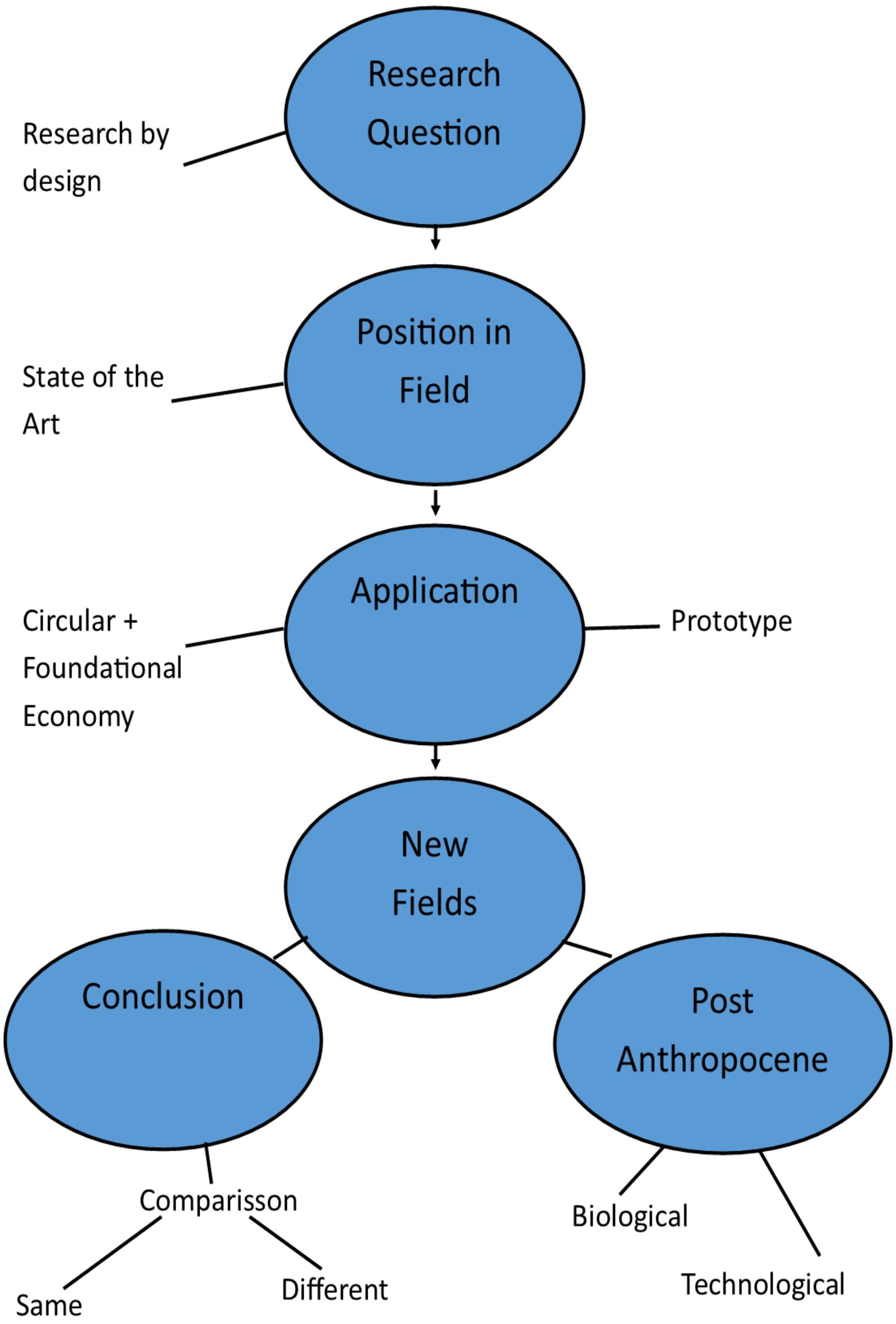

Figure 5: Diagram of Research (Jones, 2021)

To summarize the scope of the work and to provide a shape for this dissertation two graphic representations have been constructed. A model for the research is represented below (see Figure 5). Using the above format as the basis for the research work this dissertation is framed as demonstrated by the following illustration (see Figure 6). The dissertation follows a path and describes the research which reflects the thinking that led to the design and establishment of the Mushroom Garden growing system. It also reflects the continued development of the system and in its application as an example of an energy efficient, sustainable food production unit that is a perfect fit to new and emerging economic systems and ideas.

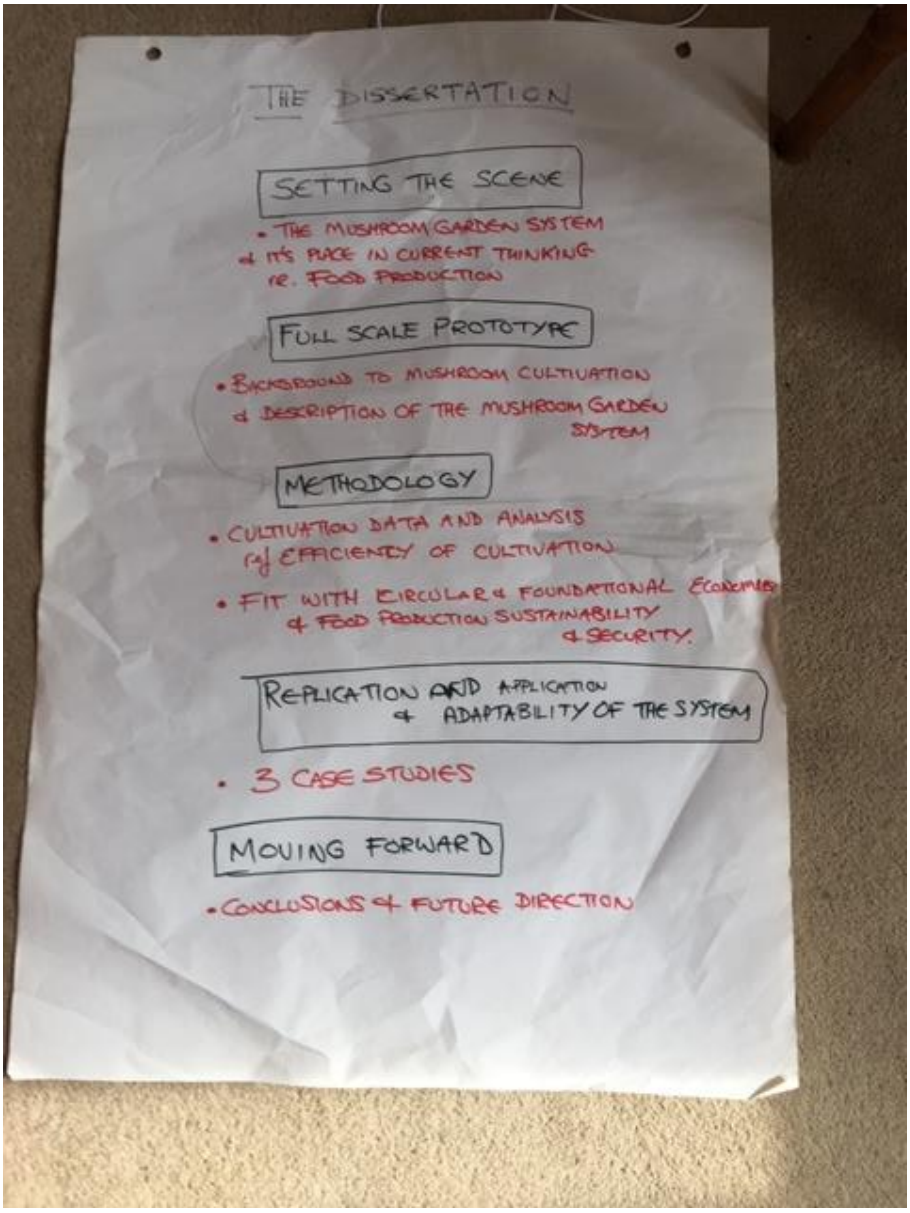

Figure 6: Shape of the Dissertation (Jones, 2020)

1.6 Systemic Design

As stated above this is a non-reductionist dissertation and therefore fits with a Systemic Design approach. This approach is essential for complex problem solving or collaborative thinking and is a very successful tool to help to understand how to design (in this case a growing system prototyping). The approach not only considers the core challenges or problems but also how the challenges interact with the environment both natural and human and other societal systems. It contrasts with the traditional design approach which is described by Ryan (Ryan,Alex 2016 as an approach that divides and compartmentalises systems and employs linear processes that sub divide workflows into neat boxes and sequential decision making cycles. He also suggests that the reductionist models ignore:

> *"messy realities in favour of the abstract, the idealised and the measurable"*(Ryan, 2016)

Peter Jones describes Systemic Design as an useful, or even essential approach when designing systems and processes within a complex environment where sociological, technical and environmental forces are present(Peter Jones & Kijima, 2018). The Mushroom Garden system and its application operate in situations where sociological, economic, environmental, and technical forces are at play therefore lends itself perfectly to a systemic design approach. Jones also indicates that stakeholders should be prominent in the design process. This resonates with the Mushroom Garden's design, development, operation, and application as the main stakeholder is the researcher practitioner (myself as the farmer using the system). The application of the system, as demonstrated by the case studies, places great importance of close consultation and involvement with stakeholders e.g., practitioners, consumers, and educators. An important element of Systemic Design is the use of prototyping in the design process and the Mushroom Garden growing unit is a full-scale working prototype where trial and error is central to the research e.g. changing the lighting regime. Various misting and watering regimes were also investigated. Every change in the conditions were recorded as was the effect in terms of yield and nutritional values of the mushrooms and the processes adapted where necessary.

To summarise this chapter, the thinking process underpinning the research and development starts with an overview of the Mushroom Garden System within the global food production scene. This involved researching alternative food growing systems in general and the place of Shiitake and Wood Oyster mushrooms as a high-value, high-quality nutritious food. The research then required a firm methodology which necessitated a complex approach. This involved looking at the growing system in technical terms, analysing energy input and yields and the quality of produce. It was also coupled with an opportunity to apply the system to a range of growing opportunities that fitted the new economic models and the challenges faced by local and global food production. Using the full-scale prototype as the "laboratory", technical research was undertaken, and adaptations made to make the system more efficient. Areas where further improvements can be made to production methods and techniques were also highlighted. The research is firmly embedded in a Systemic Design approach. In order that the application of the system could be demonstrated three case studies were followed which demonstrated the flexibility in the application of the system. Finally, any conclusions that could be drawn from the research and what potential applications could be developed in the future have been considered.

2 CURRENT THINKING AND RESEARCH INTO SHIITAKE AND WOOD OYSTER CULTIVATION.

2.1 ORIGINS AND USE OF EXOTIC MUSHROOMS

Fungi, of which mushrooms are one of the forms which we can see with stalks and caps, have been used for thousands of years as a source of food, medicinal uses or for their mind changing properties (Davey, n.d.). Although there are millions of species of fungi around the world, the UK is home to approximately 3,000 major species. The main reason for cultivating mushrooms is for food use. However, although some non-edible species are poisonous if eaten, some of these have applications in medicine. Fungi are essentially split into two groups – Decomposers (DEC) and Mycorrhizal (MR). Decomposers are the group more commonly recognised as 'mushrooms', of which there are a range of species. As they grow on decaying matter, they break down plant and lignocellulosic matter to obtain their nutrients. Mycorrhizal species on the other hand, grow by forming symbiotic associations with the roots of living plants. These species include various varieties of Truffles (*Tuber spp)* which grow underground, and for this reason, cultivating them is complicated and unpredictable, hence the high prices that they command when available.

Mushrooms in the UK are a high value horticultural crop. Various types of mushrooms are grown commercially - the most common being the white *Agaricus bisporus*. These are sold as cremini, buttons, open, closed or flats, depending on their stage of development and there is also a brown, known as chestnut mushrooms. Other *Agaricus* species such as the horse mushroom, *Agaricus arvensis*, have been grown commercially but the yield is lower and consumer demand is less. Valued for their culinary and medicinal properties, speciality mushrooms have been enjoyed locally and in small quantities by Native American and ethnic populations, and widely used for centuries by Asian cultures. The shiitake mushroom is one of several marketed speciality mushrooms today, including Oyster, enoki, wine cap, maitake, and pompom. Behind the common button and, the shiitake mushroom is the second most widely produced mushroom in the world. Indeed, American production of shiitake has increased faster than any other speciality mushroom. Shiitake contains all eight essential amino acids in better proportions than soybeans, meat, milk, or eggs as well as containing a good blend of vitamins and minerals including vitamins A, B, B12, C, D and Niacin. In addition, shiitake mushrooms are a popular source of protein in Japan and are a major diet staple in China as well as other parts of the Pacific Rim. It is estimated that approximately 50% of the annual 5 million metric tons of cultivated edible mushrooms contain functional "nutraceutical" or medicinal properties.

The shiitake mushroom is highly desirable from a product development viewpoint and has strong opportunities for growth within the existing groceries market. This is because it is already popular as an exotic variety among consumers and food producers alike but is only produced in limited supply within the UK. However, there is consensus among higher-end mushroom consumers that the shiitake mushrooms produced in the UK are of a higher quality in terms of taste, texture, and freshness for home consumption. This is understandable as mushrooms do not travel well - quality deteriorates very quickly after seven days in a chiller. Freezing is used sometimes for long haul distribution. However, ice crystals tend to break up the flesh of the mushroom and render them infirm when thawed which affects the appearance and texture. Cultivation of Oyster mushrooms is on the increase in Europe, and this is leading to a higher market share. Again, shelf life and preservation are a challenge so that UK grown Oyster mushrooms are becoming more popular with consumers. Shiitake and Oyster mushrooms are often dried and sold as preserved food in packages. These must be rehydrated by soaking in water before using. Many people prefer dried mushrooms to fresh, considering that the drying process draws out the superior umami flavour from the mushrooms as proteins are broken down into amino acids. The stems are rarely used, primarily because they are harder, and take longer to cook than the soft fleshy caps.

2.1.1 Specific Properties of Shiitake and Wood Oyster mushrooms.

Extracts from Shiitake and Oyster mushrooms have been researched for health and nutritional benefits, ranging from anti-viral properties to possible treatments for severe allergies, also being antioxidant. The recent findings are discussed in the literary review section. A native of tropical environments, shiitake mushrooms require heat, moisture, and plenty of nutrients to fruit. Commercially, they are usually grown in bags of growing medium inoculated with shiitake spawn. A very similar regime is required for Oyster mushrooms and optimum conditions for cultivation are discussed in the literature review sections. Shiitake mushrooms have brown caps ranging in size when fully opened from 2 to 8 cm. with a white, speckled, circular pattern. Occasionally when they mature, they may show brown fissures with a network of white cracks, as shown. This is more common in externally grown mushrooms due to drying and is not common in those cultivated using the Mushroom Garden system. Oyster mushrooms have fan shaped caps ranging in size from 2 to 10 cm. and four colour variations are cultivated at The Mushroom Garden - grey, brown, yellow and pink.

The study of fungi as a source of food and nutrition, and their potential health benefits, is a relatively new field of research in the western world and has only developed as a serious topic for academic study in the last 20 years. This period has also seen a tremendous growth in the general public's interest in mushrooms and fungi in general with publication of many books. These look at all aspects of the fungal kingdom from basic identification handbooks to publications on edibility (or otherwise), medicinal uses, psychoactive properties and. of course, fungal folklore. The last ten years has seen an explosion of information (true and false) regarding fungi on the internet and social media which has fuelled the interest in alternative lifestyle choices to explore the use of fungi for leisure experiences, food and wellbeing. For the purposes of this work evidence for the therapeutic and nutritional benefits of only Shiitake and Oyster mushrooms will be considered.

Articles in this field tend to use the terms "mushrooms" and "fungi" as interchangeable descriptions of the organism studied, although sometimes the term "toadstool" may still be seen. The use of these terms is based in western (especially British and Irish) culture and is not useful in describing spore bearing organisms. In general, the word "toadstool" has been used to describe poisonous or inedible fungi, and "mushrooms" to describe edible species, and often with a great deal of ignorance. The word "mushroom" is accepted as a description of a member of the fungi kingdom which has a stalk and cap-fruiting body, i.e., a spore-releasing mechanism, therefore all toadstools are mushrooms by this definition.

2.1.2 Shiitake Mushrooms – Lentinula edodes

Shiitake is a native of south-east Asia, well suited to the warm and moist environments of Japan, the Korean peninsula, and parts of China. It does, however, require a shock to encourage fruiting which is provided by a sudden change in temperature in the wild as autumn approaches. It is very hardy and can survive in a very wide range of temperatures from +30^{o} C to -15^{o} C. It is a saprophyte fungus, which is a wood-rotting fungus growing on dead or dying hardwood trees. The Mushroom Garden cultivates Shiitake on two types of substrates (i), oak chip and sawdust and bran blocks (approximately 2kg weight) and (ii) larger (10kg) blocks of similar substrate but with added straw which makes up about 90 % of the block. Shiitake has been cultivated in Japan since the thirteenth century using log inoculation techniques and this traditional method was used almost unchanged until the late 1900's when interest in mushroom cultivation and a more scientific understanding of the process led to the development of cultivation techniques in the USA using wood chip and sawdust. This, today, is the favoured means of commercial production of Shiitake.

Shiitake mushrooms are now widely cultivated all over the world and contribute about 25% of the total yearly production of mushrooms. The Mushroom Garden cultivation system is specifically designed for small to medium scale Shiitake production of up to 200kg per growing unit per week as compared to commercial growers that can easily be growing 10 tonnes per week Shiitake and Wood Oyster mushrooms

2.1.3 Wood Oyster mushrooms. Pleurotus ostreatus

This mushroom is common in many parts of the world and is a very successful saprophyte in the wild, which is a wood decomposing fungus living on dead or dying hardwood trees. It is very versatile and nonspecific in its choice of growing substrate and will grow on most organic material such as straw, hay, paper and recently has been successfully cultivated on spent hops from breweries and used ground coffee. Originally cultivated commercially in Germany during World War 1 as a food source it is now cultivated worldwide on very large-scale production units commonly growing 10 tonnes per week. The most common substrate for commercial cultivation is straw and this is The Mushroom Garden's chosen substrate in 10kg blocks. The Mushroom Garden grows four strains of Oyster Mushrooms – the Grey, Yellow, Pink and the Brown -all are the *Pleurotus* species. As mentioned above there is a great deal of public interest and academic research into the nutritional and health benefits of Shiitake and Oyster mushrooms. There follows a review of both these issues. The review of academic research refers to published works in journals and university-based dissertations and publications whereas the public interest information derives from privately published and privately funded books and publications. At this stage care is taken not to place excessive weight on one source or the other.

As mentioned above the fungal kingdom has, over the last 20 years, created a great deal of interest in both the nutritional and medicinal properties of mushrooms in general and Shiitake and Oyster specifically. Interest in and evidence of are two very different things, however; this review will be approached in two ways - firstly by reviewing the non-academic publications, mainly from books and the internet and then the academic publications in recognised journals and other accepted sources.

2.2 Nutritional and Health benefits of Shiitake and Wood Oyster

The Nutritional and health benefits of Shiitake and Wood Oyster mushrooms have long been championed in the far Eastern world and has only within the last 50 years or so become a point of interest to the Western world. While it is important not to make claims of a medicinal nature in a dissertation like this it is well worth noting the widely published evidence of the nutritional benefits of these fungi and to comment on their place in a healthy balanced diet. "Lifestyle choices "is probably the preferable term when discussing these matters, rather than reporting health benefits. The website whfoods.org (George Mateljan Foundation, n.d.) is the on-line arm of The George Mateljan Foundation, an US based not-for-profit foundation with no commercial or advertising interests. Their mission is to advise people of the healthiest foods to eat and how to cook them for optimum health benefits. There follows a series of statements that they make relating to Shiitake mushrooms. They recommend a 5g dried Shiitake daily serving in food for the following effects:

Lower blood level of inflammatory messaging molecule MIP -1 Alpha (Macrophage inflammatory protein 1alpha) which leads to a lower inflammation response.

Increases ant-inflammatory molecule interleukin.

Both these effects therefore help to inhibit inflammation in the body.

Provides biotin (Vitamin B1) also contains lentinavidins which are proteins unique to Shiitake which binds to the biotin molecule and therefore keeps it in the body.

Vitamin B1 is essential for healthy skin, hair, eyes, and liver function.

One daily serving of dried Shiitake provides 72% of the body's daily copper need – this is achieved as copper is essential for the efficient functioning of the laccase enzyme in fungi which has many beneficial effects for saprophytic fungi, for instance, helping to break down lignin in woody plants. Therefore, digesting the fungus which includes the copper bound laccase releases copper into the human body.

Shitake has a very high concentration of eritadenine, an alkaloid that inhibits the angiotensin converting enzyme (ACE) which constricts blood vessels and therefore raises blood pressure. The eritadenine therefore helps the body to control blood pressure. It may also have cholesterol reducing properties.

Contains Glucans which are polysaccharides, especially Beta-Glucan. Recent research has shown this polysaccharide to have a wide range of powerful benefits to man, such as:

Boosting the immune system

Antioxidant properties – i.e., removal of cancer linked free radicals in the body)

Strengthens the endocrine system – the endocrine system is made up of glands that produce the body's hormones which are essential for many bodily functions and development.

Controls blood sugar levels.

These observations are backed up by other on-line sources for example (Axe, 2018) Dr J Axe is a natural remedies nutritionist and has founded one of the most visited natural health website in the world (drrAxe.com), which has over 15 million monthly visitors, where the main topics include nutrition, natural medicine, fitness, healthy recipes**,** home remedies and trending health news. In the web page cited he discusses eight health benefits of Shiitake mushrooms. The information is independently fact checked. The information on the website regarding Shiitake mushrooms is like the above with a few exceptions e.g.

Shiitake contain Lentinan a polysaccharide that is believed to boost the body's natural immunity. Shiitake mushrooms are unique in that they contain all eight essential amino acids (the building blocks of proteins) and the essential polyunsaturated fatty acid linoleic acid. Lack of linoleic acid causes skin and hair problems. There is some evidence that Shiitake mushrooms help to promote oral health by decreasing the presence of oral microbes. The growing trends in healthy foods has led to several web sites being established with the aim of informing readers of the benefits of natural, unprocessed foods. The dual aim of education and providing practical advice about how to prepare meals with natural products is becoming widespread on the internet as demonstrated by the web page Food as Medicine,(Healthbenefitstimes, 2019.) his web-site is a health information site with a goal to provide readers with a particular focus on natural food and alternative health information. Their mission is to arm readers with knowledge about herbs and food nutrition, its benefits, and traditional uses.

They also have extensive information on Oyster mushrooms with the health benefits summarized below, some of the benefits are like the Shiitake such as immune system boosting properties and anti-inflammatory properties especially for oral infections and tooth decay, but with the following specific to Oyster mushrooms, *Pleurotus ostreatus:*

Maintaining blood sugar levels by raising insulin sensitivity

A source of vitamin B2-essential for red blood production and therefore reduces anaemia.

Vitamin B5 helps to maintain optimum levels of metabolism and helps convert carbohydrates to energy therefore boosts the body’s energy resources.

Contains numerous trace elements that aid nerve transmitter activity.

It can be argued that the most high-profile proponent of the benefits of fungi to humankind and the planet is Paul Stamets. He has published two ground-breaking books which has shaped the world’s thinking about the fungal kingdom. *Growing Medicinal and Gourmet Mushrooms* (Stamets, 2000), *Mycelium Running* (Stamets, 2005) In these publications Paul Stamets takes a wide-angle view on how the fungal kingdom can benefit the environment and mankind and interestingly touches upon two elements that will be addressed in this research, that is the influence of habitat/environmental conditions on the nutritional content of mushrooms and the influence of light exposure on the vitamin D content of mushrooms. These are discussed in section 2.2.

Given the current interest in healthy eating, mushrooms in general, according to Stamets, tick most if not all the right boxes e.g.

Protein rich – Shiitake averaging protein 33% protein and Oyster Mushrooms 26%

Low in simple carbohydrates

High in complex carbohydrates -polysaccharides

High in antioxidants

Low in fats

No cholesterol

Good source of some vitamins

High in fibre

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There are also early signs that some mushrooms inhibit potentially damaging enzymes in the human body, such as Aromatase inhibition with the result that breast cancer growth is limited. Both Shiitake and Oyster have this property and 5-alpha reductase inhibition limits the growth of prostate cancer. Having considered the evidence from what can be described as “Non-Academic” sources above it underpins the thrust of this research that Shiitake and Wood Oyster mushrooms are nutritious healthy and wholesome foods which can be cultivated successfully in many locations and situations.

The following section focusses on the medical and scientific research into the health benefits of both Shiitake and Wood Oyster mushrooms. The reason for highlighting the latest research in the medical and scientific community is to further underpin the reasoning behind cultivation of these fungi rather than other species of fungi or other foods.

Mushrooms as therapeutic agents have been the focus of a number of research programmes over the last 20 years, including Rathee *et al*. (RatheeI, RatheeII, RatheeII, & KumarI, 2012) In his paper, he reviewed published literature on the therapeutic benefits of 43 species of mushrooms and reported a wide range of benefits to humans. For the purposes of this review the focus will be on the research relating to Shiitake (*lentinula edodes)* and Oyster (*Pleurotus ostreatus*) mushrooms. The main findings were that Shiitake and Wood Oyster had many beneficial activities. The activities identified from Shiitake tracts were as follows:

Antioxidant - which in lay terms is anticancer activities, Hypocholesterolemic (cholesterol lowering properties), immune system boosting properties and antimicrobial and antiprotozoal properties. Wood Oyster had a more focussed range of activities namely Antioxidant and Hypocholesterolemic. Anecdotal evidence of the immune system boosting properties of both Shiitake and Wood Oyster mushrooms has existed for many years in the far East and was the subject of a research programme by Chandra *et al*. (Chandra, Lawrance; Alexander, Heather; Traoré, Djibril; Lucas, Edralin A; Clarke, Stephen L; Smith, Brenda J; Lightfoot, Stanley A; Kuvibidila, 2011)

2.3 Optimum conditions for cultivation of Shiitake and Wood Oyster Mushrooms

The Mushroom Garden System has been developed by practitioners and growers therefore it is of crucial importance to the system to investigate the optimum conditions to create the most consistent high value product. The literature review covers a range of publications from web sites and books to published academic research. As the two fungal species under consideration may need slightly different conditions, Shiitake cultivation will be considered first and then Wood Oyster.

2.3.1 Shiitake (Lentinula edodes).

Paul Stamets is one of the world's leading exponent and promoter of mycology. He has published numerous ground-breaking books and papers of which his 2000 published *Growing Gourmet and Medicinal Mushrooms* (Stamets, 2000) is considered a classic which is consulted by academic researchers, commercial growers and amateur growers alike. Paul Stamets suggests the following optimum conditions for fruiting the most common gourmet fungus, Shiitake (*Lentinula edodes*). The environment has several variables to be considered:

Fruiting Temperature:	16-18^{o} C
Average Relative humidity:	60-80 %-(see below).
CO2:	less than 1000ppm
Air exchange:	4-8 times/day
Light:	1000-2000 lux at370-420nm+

Stamets makes some interesting observations and suggestions as follows to explain how he has arrived at the above recommended values. He found that changing light intensity at various stages of growth can improve yield. Lux below 500 encourages elongation of the stalk during the initial growth period whereas fruiting improves with Lux of over 500. This changing of light intensity would be difficult in the Mushroom Garden system as the growing room has to have mushrooms growing at various stages to ensure that there is a consistent supply of produce. It also appears that changing the UV wavelength can encourage "pinning", i.e., the emergence of the fruiting body from the surface of the substrate. Again, this would not work in the Mushroom Garden System for the same reason noted above relating to the requirement for continual fruiting.

It is not a surprise to find that these variations in light intensity and wavelength influence development and growth given that the natural world has variations in light intensity in the daily cycle and of course light spectrum not only changes in the daily cycle but also seasonally which contributes to the "shocking" of the mycelium to encourage fruiting. Rapidly decaying wood encourages quicker growth (in US Shiitake will grow on several hardwood trees but in UK we are confined to Oak with up to 20% Beech. Trials with oak chip of various ages of decomposition would be interesting. The Mushroom Garden system uses wood chip and sawdust that has at least a 12-month decaying period. Varying the humidity regularly during the day, from between 70% and 100 % Relative Humidity, reduces the build-up of a green mould (*Trichoderma*) on the growing blocks, and it is also a good idea to hose down the blocks twice a day. These measures have been adopted by The Mushroom Garden system, using humidistats and a spraying regime, and proved successfully to reduce *Trichoderma* cross infections. Stamets' comments that spent Shiitake substrate can be sterilised and incubated for Oyster mushrooms has been noted. This is to be incorporated in future into the Mushroom Garden approach as it not only reduces the requirement for Wood Oyster cultivation, but it also supports the principles of the circular economy.

A paper in the *Agrodok* series of publications("Agrodok booklets on Health matters," n.d.) describes and analyses small-scale mushroom cultivation in rural India. It is very similar to western methods in that the substrate is sterilized, cooled, and bagged in plastic for inoculation and then sealed with a breather for mycelium colonisation. The following extract is describing the fruiting stage. If the plastic is removed too early or too late, yields will be affected. De-formed fruiting bodies during the first flush are a sign of a spawn run being too short or CO2 too high during incubation. Strains differ in mycelial growth rate. While 60 days is sufficient to mature one strain, another strain would yield many deformed mushrooms after the same period of maturing. If the temperatures are rather low and a suitable strain has been used, high-quality donko mushrooms can be harvested. If the humidity is also relatively low (60 to 70%), then cracks may appear in the caps of the most expensive quality in the Far East, which is called "flower winter mushroom" hua dong gu in Chinese. Below is a table (Figure 7) showing optimum time, temperature, light intensity, and relative humidity for Shiitake cultivation on sterilised substrate in plastic bags.

Table 1: Optimum conditions for Shiitake cultivation (Jones, 2020)

Stage/activity	Days	Temp.Deg C	Light Intensity (Lux)	Relative Humidity %
Incubation	30-120	20-30	None	65-70
Induction of Fruiting bodies	2-4	10-20	500-1000	85-95
Harvesting	7-14	12-18	500-1000	60-80

Recovery	7-21	20-30	None	65-70
Induction of 2nd Fruiting	2-4	10-20	500-1000	85-95

The parameters here are very similar to those recommended by Stamets discussed above. The Mushroom Garden system has adopted most of these recommendations within the limitations mentioned regarding variation in lighting regimes which are not compatible with a small-scale growing process that needs to be producing daily. Wong-Chull *et al*.(Wong-Chull Bak, n.d.) in their *Mushroom Growers' Handbook* discuss log cultivated Shiitake and primarily *Trichoderma* infections. The Mushroom Garden has seen similar infections in the grow bags. The natural remedy to prevent and control this infection (which does not harm the Shiitake mycelium or growing body but competes for nutrients and therefore can reduce yield) is to control temperature and humidity as described above. Log growers grow outside so have difficulty in doing this due to weather conditions, however The Mushroom Garden system finely controls both elements and avoids serious *Trichoderma* problems. The paper also states that direct sunlight encourages *Trichoderma* growth which is at odds with The Mushroom Garden's experience – *Trichoderma* infected blocks, left out in the sunlight and the weather lose the tell-tale green infection. This will need further investigation under controlled light environment using light that mirrors daylight wavelength matrix.

2.3.2 Wood Oyster (Pleurotus ostreatus)

Referring again to Stamets, the conditions noted below are not dramatically different from those that Shiitake favour, however some notable differences are to be noted:

Fruiting Temp: 10-21^o C

For best colour of caps: Temperature 16^o C

Average Relative humidity 85-90%

CO2: less than 1000ppm- Oysters very sensitive to CO2 build up.

Air exchange: 4-8 times/day

Light: 1000-2000 lux – Oysters very sensitive – high lux levels enhance mushroom cap colour.

There is no need to vary humidity during the growing or second flushing stages. It is important that the air change regime is consistent with Shiitake to avoid CO2 build-up. The optimum temperature for developing cap colour (16^o C) is in the middle of the Shiitake fruiting temperature range. These findings are encouraging as the Mushroom Garden system can therefore grow both Shiitake and Wood Oyster in the same environment. This is very important to be able to offer both products to customers.

The web site Alohamedicinals.com has an on line *Mushroom Grower's Handbook for Oyster Mushrooms* (*Mushroom Grower's Handbook for Oyster Mushrooms,* n.d.) In the life cycle of *Pleurotus* mushrooms there are two stages: the vegetative stage and the reproductive growth stage. Generally, some kinds of stimuli are needed for the shift from mycelial (vegetative) growth to the fruit body formation (reproduction) phase. This is sometimes termed "shocking ". These stimuli include abrupt changes in temperature, humidity, gas concentration, light and nutrient reserves, and physical stimuli. In nature which can be replicated in the cultivation process, among them, a sharp temperature drop is the most effective in fruiting induction for most mushrooms. Fruiting is induced by low temperatures ranging from 10 to 15℃ in *P. ostreatus*. This is the temperature range in the Mushroom Garden's growing room and fortunately it is also the temperature range that shocks Shiitake into fruiting, making it possible to encourage fruiting in both species in the same environment. This range of temperature is also ideal for the development of Wood Oyster and Shiitake fruiting bodies.

The handbook also instructs growers to consider the CO2 gas concentration in the substrate containers during spawn run and the ambient CO2 concentration during fruit body development. Under high CO2 levels or with less frequent ventilation, mushrooms produce long stipes with tiny caps, while they produce short stipes with broad caps under low CO2 levels or frequent ventilation. For *P. ostreatus*, a CO2 concentration higher than 1, 000 ppm will produce stipes that are too long and result in mushrooms of lower quality, therefore the ventilation system in the Mushroom Garden System, air changed every 45 minutes keeps the CO2 concentration below this level.

2.4 BIOTECHNICAL APPROACHES TO FOOD CULTIVATION

The combination of the two words Biology and Technology in terms of food production has long been associated with what many would regard as negative developments, including the use of chemical insecticides, the use of antibiotics to boost meat production or the genetic modification of plants and animals. Genetic modification and the motivations for its opposition is described by Ofoe (Ofoe, 2020) and shows how many Green environmentalists are suspicious of linking technology to food production. However there has recently been a departure from this traditional view of using technology to change biology to using technology to work with biology to enhance food production in a non-invasive way. As an example of governments supporting such innovation a £16 m fund was established by the UK government in 2016 to support UK firms developing processes to enhance global food production and food security (Uk Government, 2016). One of the projects was to develop a fully automated commercial vertical hydroponic crops system in indoor farms. Another project supported was by Hydrogarden Wholesale Supplies Ltd. That developed a fully automated commercial vertical hydroponics indoor system (Vydrofarm) adapted for both cold and hot/humid climates. It incorporates a set of proprietary technologies and knowledge – including special LED lights, specific nutrient regime, and biodegradable growing media – to deliver 30% more crop yield, compared to existing growing technologies, and reducing by half the normal growing period. Vydrofarm delivers significant impact on crop production, making it feasible to grow nutritionally rich microgreens and medicinal herbs in urban and peri-areas, particularly rehabilitating redundant buildings, brownfields sites and high-polluted land. It also improves food security and increases the supply of nutritious and better-quality produce to a larger amount of population. This is a prime example of how there a global shift by governments in the thinking about food production Innovation in efficiency of energy use and growing spaces for production has been increasingly seen as part of the answer to food sustainability and security. The Mushroom Garden system fits perfectly with this approach.

Patrick Heffer has reviewed a number of papers investigating the use of biotechnology to improve food production in Rwanda (Dusengemungu et al 2019). In the frame of this paper, "biotechnology" is considered in its broad sense, that is the use of biological processes or organisms for the improvement of the characteristics of plants, animals, micro-organisms or food derived thereof. This includes, but is not limited to, modification and enhancement of living organisms at the molecular level, frequently dubbed as "modern biotechnology." The paper concentrates on recent developments of biotechnology use in the seed industry. It presents biotechnology as providing powerful and useful tools, in a continuum of technical evolution that contributes or could contribute to the improvement of crop production, food quality and safety, while preserving the environment. It also addresses the complex regulatory framework surrounding modern biotechnology, as well as tools in the pipeline, and intellectual property aspects related to the technology. It analyses current and potential applications of biotechnology in developing countries and countries with economies in transition. Finally, the paper is limited to plant biotechnology. It does not address the use of biotechnology in animal breeding or food processing. It is important to note that an approach using In vitro cultures help to protect purity of species and avoid disease transmission. This approach again underpins the movement to use technology in a non-invasive way to improve production and sustainability, two of the themes underpinning the Mushroom Garden system.

Biotechnology usually refers to using technology to change the biology of foods (plants and animals) and often relates to genetic modification however it also can mean the use of technology to improve growing systems. There follows some cutting edge research on the lighting regime for mushroom cultivation. Firstly research into energy efficient cultivation of Chlamydomonas reinhardtii for lipid accumulation under flashing illumination conditions. (Kim, 2014). This research is aimed at the energy-efficient cultivation of an algae rather than a fungus and looks at the photosynthetic activity under flashing light. Fungi do not have photosynthetic processes; however, results show that under high intensity flashing light at a rate of 1:1 there was an energy saving of 62.5% with no reduction in biomass or lipid production. Therefore, using intermittent light from LED sources produced very large savings without reducing the yield or quality of the crop. This is an exciting discovery in the field of algae cultivation and would be interesting to see if intermittent lighting from LED would produce similar effects in mushroom cultivation. We already know that light intensity and colour does affect the growth and chemical composition of Oyster mushrooms, however using intermittent light has not been investigated. Such an experiment could easily be performed in the Mushroom Garden growing room, and it is currently being investigated by The Mushroom Garden.

The importance of light in the growing system is further underlined in the following research projects. A very exciting piece of work by Huang *et al*. (Huanga, 2017) goes to the heart of what is investigated in one aspect of this research. That is how to make the Mushroom Garden system more energy-efficient for rolling out in several locations and situations. Huang found that light at the blue end of the spectrum not only encourages the production of health-beneficial compounds (antioxidants and polysacharides) but also increases the biomass that is the yield of mushrooms. It is also interesting to note the conditions under which the mushrooms are grown, that is an 8hr photoperiod at 26^{o} C with 85% humidity inside growth chambers. This growing temperature is much higher than the Mushroom Garden system. It would be preferable in the Mushroom Garden system to use less energy in the form of heat as the *Pleurotus* yields perfectly well at $15\text{-}18^{0}$ C.

Further work by Sano *et al*. (Hiroaki & Takatsugu, 2007) on the molecular and genetic level of primordial growth has found other interesting light controlled processes, specifically in gene transcription. Transcribing of a gene means the creation of proteins from the DNA pattern within the gene, that is how living organisms develop and grow. The gene transcribes in all stages of fruiting body formation but is more abundant in immature fruiting bodies, so that the most active growth and development stages are at the start of the fruiting process. Primordial aggregated mycelial cells grown in blue light have more of the transcript than those grown in the dark suggesting that the blue light activates the gene to start creating the protein. The practical outcome, therefore, is that light on the blue end of the spectrum will encourage more growth and development of fruiting bodies especially at the early stages of growth. This is again offering further scope for changes to the Mushroom Garden system lighting regime.

Of greatest interest with regards to energy efficiency is the use and effect of LED lighting of the same lux compared to ordinary fluorescent lighting in the growing rooms. Sing et al (Sing,Devesh, 2015) investigated the effects of LED in greenhouse plant cultivation and found some interesting results. Their aim was to look at more efficient greenhouse lighting using LED. They only looked at plant growth under LED not fungi, however the principles of the approach could well be applicable to mushroom cultivation and will be further investigated in The Mushroom Garden System. Light energy is an important factor for plant growth. In regions where the natural light source (solar radiation) is not sufficient for growth optimization, additional light sources are being used. Traditional light sources such as high-pressure sodium lamps and other metal halide lamps are not very efficient and generate high radiant heat. Therefore, new sustainable solutions should be developed for energy efficient greenhouse lighting. Recent developments in the field of light source technologies have opened new perspectives for sustainable and highly efficient light sources in the form of LEDs (light-emitting diodes) for greenhouse lighting. This review focuses on the potential of LEDs to replace traditional light sources in the greenhouse. In a comparative economic analysis of traditional vs. LED lighting the introduction of LEDs is shown to allow a reduction in the production cost of vegetables in the long run (several years), due to the LEDs' high energy efficiency, low maintenance cost and longevity. To evaluate LEDs as an alternative to current lighting sources, species-specific plant response to different wavelengths is discussed in a comparative study. However, more detailed scientific studies are necessary to understand the effect of different spectra (using LEDs) on plants physiology. Technical innovations are required to design and realize an energy efficient light source with a spectrum tailored for optimal plant growth in specific plant species.

This review by Sing *et al*. cited above summarizes the research work done on energy-efficient greenhouse lighting with LEDs. Economic analysis indicates that LEDs can reduce the electricity cost, and investment (high capital cost) will be returned in the long-term operations in greenhouse industries. Solid state lighting with LEDs offers high luminous flux and luminance with low radiant heat. LEDs offer the possibility to optimize the light distribution for small and large greenhouses and also in multi-layered farming in greenhouses because LEDs (due to low radiant heat) can be placed close to the plants. Moreover, optimization of spectral quality to improve plant growth (photosynthetic efficiency, nutritional value and regulation of flowering) and the inherent energy efficiency can reduce power consumption significantly. However, to utilize the full potential of LEDs as a radiation source in greenhouse industries, it is necessary further to investigate the not yet fully understood physiological processes mediating plant responses to LED light. Different light spectra have different effects on plant growth and most studies on the effect of LED radiation on plant physiology have included only red, far-red, and blue LED lights as main lighting source. Green light has been considered as photosynthetically inefficient, but even photosynthetically inefficient light can contribute to plant development and growth in orchestration with red and blue light as confirmed by some recent studies (Folta, n.d.) Further investigations are required to understand the roles of green light in regulation of vegetative development, flowering, stem elongation, stomatal opening and plant stature. Research questions such as what specific spectrum, photosynthetic photon flux density and photoperiod are required by different plant species and varieties in different developmental stages have not been conclusively addressed yet. As LED technology provides a lot of flexibility in terms of design of output spectra, adaptation of the lighting conditions to the specific needs of the plants can be achieved. LEDs offer an energy efficient approach for greenhouse lighting which can reduce the production cost of vegetables and ornamental flowers. However, the potential of this approach is far from being fully explored and more research is required to study effects of LEDs on various vegetables and ornamental plants.

This research is looking at energy efficient greenhouse plant cultivation, focussing on both the photosynthetic and photomorphogenic effects of LED compared to traditional fluorescent light. As previously discussed, fungi are not photosynthesising life forms. However, it is known that light affects both the shape, structure and molecular composition of fungal fruiting bodies and mycelia, and it is also known that certain wavelengths are more conducive both to the yields of mushrooms and the quality of the product as defined by protein, polysaccharide and vitamin and trace element content.

The variables introduced in this research, such as using light with a mix of wavelengths, plus using intermittent light, could be an approach to the cultivation of Shiitake and Oyster mushrooms and should be investigated. There seems to be broad consensus among the amateur hobbyist growers, commercial growers and academic researchers with regards to the basic conditions for Shiitake and Oyster cultivation with some very interesting adjustments for maximising yield and quality of fruiting bodies and also energy efficiency in terms of light use, frequency, intensity and wavelength and colour temperature. The conditions are summarized below (see Table 1)

Table 2: Summary of optimum Condition for Shiitake and Wood Oyster cultivation (Jones, 2021)

	4.1 Shiitake (*Lentinula edodes*)	4.2 Wood Oyster (*Pleurotus ostreatus*)
Temperature	15-20^{o} C	Researchers agree that a temperature range of 15 18^{o} C is the optimum throughout the primordial to fruiting stages. Optimum temperature for colour of caps at lower end of the scale.
Humidity	1st flush 100% for 2nd and subsequent flushes vary 70-100% several times a day to reduce *Trichoderma* infection.	85%-95%
Light- Intensity/ frequency/ wavelength etc.	Less than 500lux on the primordial stage then 500 - 2000 lux for fruiting the green uv scale.	Up to 2000 lux, Higher lux levels enhances cap colour.
CO2	Less than 1000ppm	Less than 1000ppm
Quality	Appearance and taste seem to be consistent in 1st and subsequent flushes	Appearance and taste the same for first and subsequent flushes
Yield	Over 2 flushes 30%-40% of original substrate weight.	30 – 40% of original substrate weight over 2 to 3 flushes
Air change	Every hour	Every hour

Lighting

It is interesting to note that using LED lights and adopting a regime of flashing light at a ratio of 1:1 produced an energy saving of over 60% as compared to traditional fluorescent lighting when cultivating algae without compromising yield or quality. It would be interesting to investigate whether the results can be replicated with fungi. Two other pieces of research have also produced very interesting results when illuminating both Oyster mushrooms and Shiitake mushroom with LED light at the blue end of the spectrum- there was an increase in antioxidant compounds and sugars in Oyster mushrooms and increase in protein creation in Shiitake mushrooms. These findings seem to suggest that LED lighting can not only be more efficient in terms of energy use but can also add to the quality and properties of Shiitake and Oyster mushrooms. In section 5.4 the result of changing the lighting system from fluorescent to LED will be discussed.

Temperature

Various growth stages require different optimum temperatures – this can inform us when designing the heating profiles for growing rooms – it is obviously not efficient to maintain the same temperature at all times in the growing phases. The Mushroom Garden will further investigate establishing a temperature regime linked to the growing phases of the mushrooms in order that energy efficiency is increased. The Mushroom Garden system will, in the next 12 months, implement the development of these approaches and ideas so that it becomes more efficient as a is a semi commercial system that can be sited in almost any urban or rural location and a number of environments where there is a need to produce nutritious foods in a relatively small space with a low time bound turnaround of production. It can also be fully integrated to living spaces.

2.5 A Systemic Design Approach

This sub-chapter demonstrates how the design of a mushroom growing system involves a number of inter dependent variables i.e., temperature, humidity, air quality and lighting in order that a fully replicable consistent production system can be established. Biotechnology has become an increasingly important driving force in food production. The Systemic Design approach lends itself to such a complex process which requires close interaction with individuals working the system and the community it serves. The approach also relates to the application of the growing system in communities. In a special edition of the Journal FormAkademisk (Davidova, Sweeting, & Sevaldson, 2020) the authors describe the benefits of such an approach can lead to more sustainable communities based on new economic models e.g. the Circular Economy. The authors also discuss how the approach shows how different elements within a community, both human and environmental are interlinked and interdependent and the design process can take advantage of these to create more successful communities both sociologically and economically. The Mushroom Garden system is a perfect example of how co designing a food producing system with a community can bring nutritional and economic benefits to the community.

A gigamap (seeFig.7) that illustrates the approach and is a physical representation of the work that has gone into this dissertation. It demonstrates how the two basic pillars of this work, biotechnology and application are interlinked and interdependent to each other and how the basic concept interacts with external issues in a complex and creative manner.

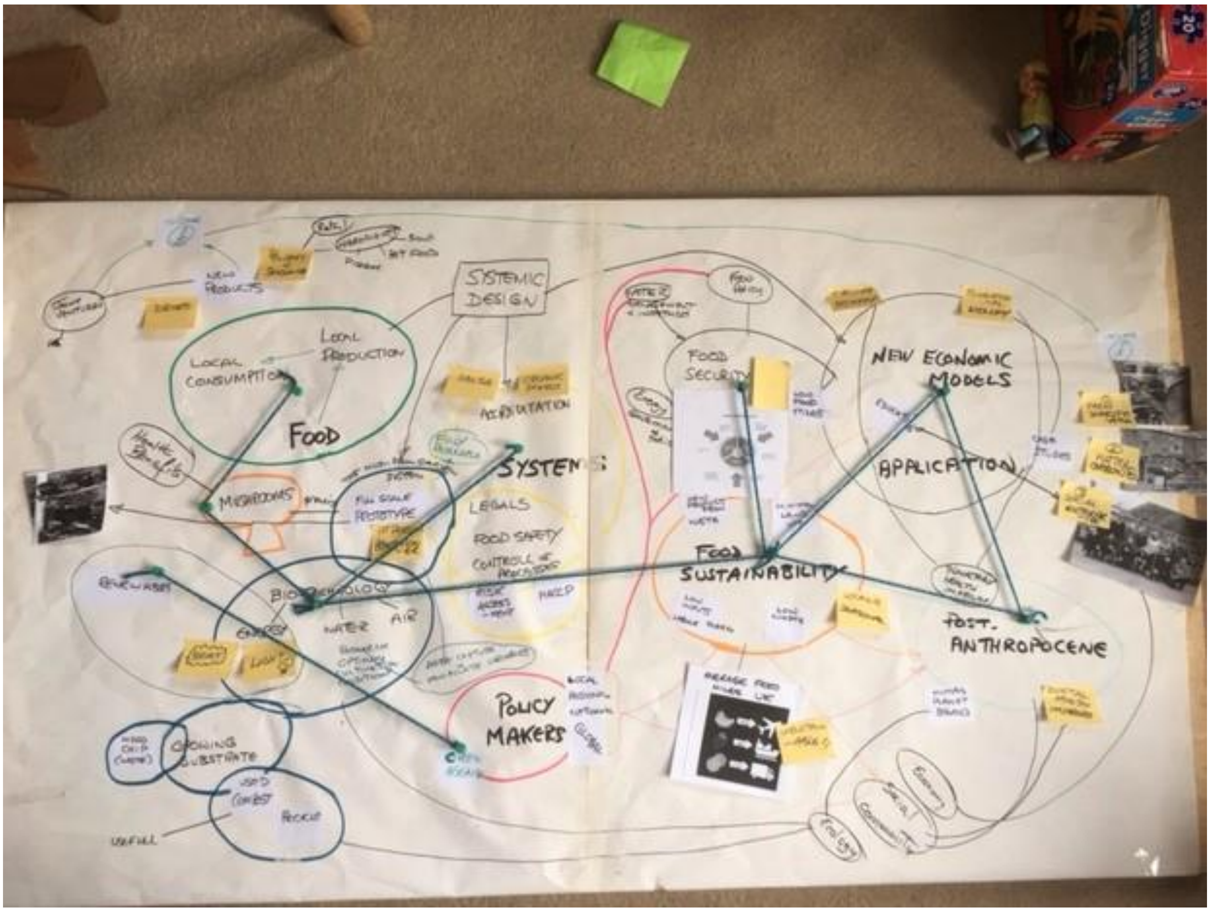


Figure 7: Giga map of the research (Jones, 2021)

3 NEW ECONOMICS AND IMPACT OF FOOD PRODUCTION

In addition to being replicable in any urban or rural setting, the Mushroom Garden System is a perfect fit for current thinking on how food is produced and how we need to re-design our local, national, and global economies in general, and food production specifically, to make them more sustainable, less wasteful, more environmentally sound and more secure. This chapter will look at how the Mushroom Garden System addresses these issues by focussing on three case studies where the system is operated for different aims. Each case study is framed by the following headings:

Sustainable food production

Food Security

Circular economy for growing food

Foundational Economy business.

Post Anthropocene

There follows an introduction to each of the above headings:

3.1 SUSTAINABLE FOOD PRODUCTION

There are many definitions of what constitutes a sustainable food system. However, they all share common threads relating to local issues such as security, efficiency of production, health and wellbeing of consumers and central to the concept of sustainable food production is that it is built on principles ecological, social, and economic values of a community and region (Kaufman, Jerome; Pothukuchi, 2000) in their definition place more emphasis on efficiency of production and use of energy, processes that are in tune with local ecological and environmental conditions and the recyclability of waste. They also note that sustainability should consider the balance between food imports into the community and local capacity. This mirrors the principles of the Foundational Economy discussed below, i.e., that production within a community should be driven by the *needs* of a community and not by the pressures of external corporations' view of what the community *wants.*

In a 2019 discussion paper (ap Gwilym, 2019) The Institute of Welsh Affairs describes the five elements of a foundational economy: the utilities, including piped or cabled services such energy, water and sewerage; retail banking; food and petrol retailing; food processing; networks and services such as rail or bus for transport and distribution of people and goods; telecommunications networks; health, education and welfare/social care.

Food retailing and processing is one of the five cornerstones of a foundational economy, thereby making a case for local production distribution and consumption of food. The paper also presses Welsh Government to redefine its traditional economic policies of inward investment through attracting large multinational businesses to Wales and focus instead on the Foundational Economy which is rooted in the community. Educating community members and the population in general about food issues, agricultural issues, and the role of global environmental changes in food production should also be central to food sustainability. The Kindling Trust, UK's definition("Definition Sustainable food," 2019.) includes not only waste reduction but also reduction of packaging and especially non-recyclable packaging. Related to reduction in packaging is the issue of reducing food miles as much of the packaging of food is to maintain quality while it is distributed sometimes on a regional scale but often on a global scale. Local need and food miles have been mentioned as drivers for food sustainability and linked to this is the local integration of food production and local consumers, for instance through restaurants, schools, health service establishments and other public institutions.

In an article on sustainable farming (Bharucha, 2013) the author highlights innovation in world farming and, focussing on issues such as water conservation and crop modification, however, the conclusion is that **participation** is key and that innovation by itself is not enough to ensure increased food production, resource conservation or social-ecological well-being. Farmers, rural workers, local groups and community leaders need to participate in innovation, rather than being treated as passive recipients of new technologies. Participatory models work — a recent analysis of 40 cases of sustainable intensification of agriculture in Africa shows the ways in which farmers, public and private-sector partners have developed, adapted and disseminated agroecological systems that have increased yields while delivering environmental and social benefits. All the cases highlight the importance of farmer engagement, peer-to-peer learning, and of developing and using local institutions.

On a global scale the charity Farming Solutions (Farming Solutions, 2016) on its web page “Why farming sustainably is so important” states four reasons to support its argument as follows:

Treats the Land Properly- land use and quality are respected therefore having environmental benefits.

Production Uses Less Chemicals- it is proven that chemicals used in agriculture can damage the soil and can also end up in our foods and our bodies.

Food Is Available at The Proper Season - sustainable farming means not exploiting land or forcing crops to grow at the wrong time of year for commercial profits. Sustainable farming helps to educate people about the growing cycles for foods.

Food Tastes better- food grown in season and naturally has enhanced taste.

It can be argued that these statements are subjective and feed a certain narrative. What cannot be denied is that public opinion and eating habits are moving towards these four statements. There follows a diagram of the various elements that contribute to food sustainability (see Figure 8).

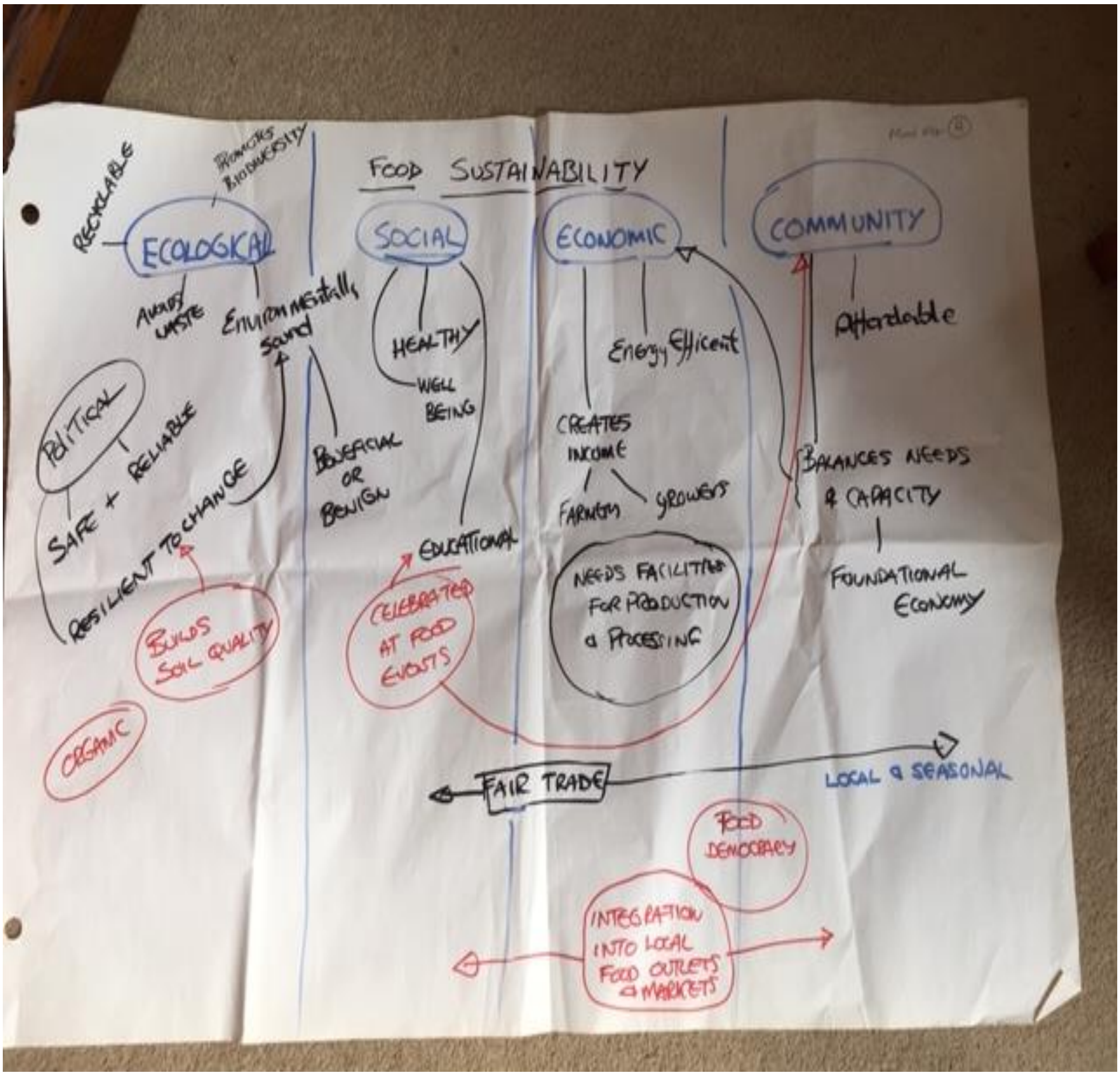


Figure 8: Diagram of Food Sustainability (Jones, 2020)

3.2 Food Security

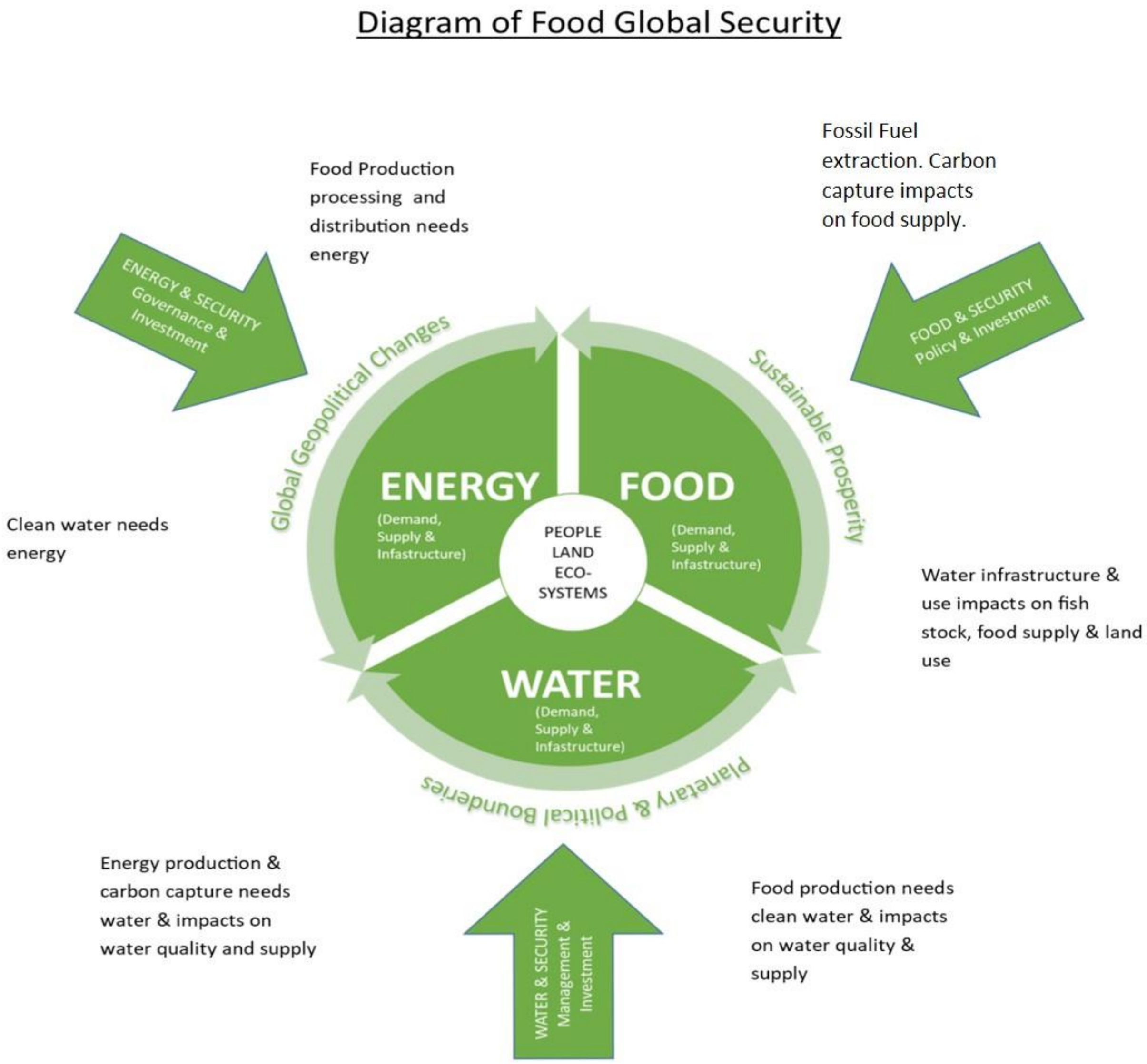


Figure 9: Diagram of Food Security redrawn by Jones 2020 based on Haddfield-Dodds (Haddfield-Dodds, 2015)

The Mushroom Garden system fits well with many aspects of food security as described in the Diagram (see Figure 9) primarily as it is a modular system that is resilient, economically sound and can be sited in rural or urban areas. This dissertation has confirmed and enhanced the energy efficiency of the system and can be an economic generator for an individual grower or a community group. The research shows that the mushrooms grown are healthy, nutritious, and safe for consumption and the spent growing substrate is an ideal mulch and compost and contributes both to soil health but also soil humidity retention. The system attracts a lot of attention and numerous groups, and individuals visit the Mushroom Garden to learn about cultivating mushrooms. Through this they get an understanding of the processes involved in food production. Having such a compact, modular, and productive system that can be established within any community also reduces food miles. The image below shows the average food miles for fruit brought into the UK from around the world. The UK is not unusual in this respect and such food miles totals are common throughout the developed world. The food miles of the produce of the Mushroom Garden, by comparison, is low. Due to the production being in the same community as the food is consumed (see Figure 10).

Figure 10: Diagram of average UK Food Miles- Cynan Jones redrawn from Klein100 Teaching resource 2020("Food miles lesson - fully resourced Geography lesson for Key Stage 2 (KS2)," n.d.)

Food security and insecurity has been the focus of much research and reporting over recent years and increasingly they are seen as both local and global issues. On a global scale over half the cases of food insecurity are on the African continent and a whole number of factors contribute to the problem. Food security is a measure of the availability of food and individuals' ability to access it. Affordability is only one factor; the issues of supply and demand also have role to play as do local and global geopolitical situations and environmental changes. Food security incorporates a measure of resilience to future disruption or unavailability of critical food supply due to various risk factors including droughts, shipping disruptions, fuel shortages, economic instability, and wars. In an increasingly unstable world (from the global to the local) small scale solutions can help to inform large scale challenges. There is an increasing trend across continental Europe to address urban food security issues with urban solutions. A network of 47 cities across continental Europe that have addressed food security issues in the cities have formed an alliance where they can learn from each other and develop good practice and influence policy makers. In this article the author explores the case for establishing such a network of Food Cities in the Uk. In their chapter(Pell & Bohm, 2019) in *Food Bigger than the Plate* (Flood & Sloan, 2019) discuss the disconnect between farming, that is, the way we use resources and labour to create food, and urban life. To many, farming is an abstract concept that happens somewhere else and is not directly relevant to modern urban citizens. This has led to a way of thinking which makes rural areas producers of food, and urban areas consumers.

They argue that re-integrating food production with urban living can re-address the imbalance and also lead to opportunities for social and economic regeneration. An interesting concept explored in the article is that of the ‘Hedge HUB’ (Horticultural Urban Growth). In essence the idea is that food growing can take place in urban spaces and is taking the farm to the city. These growing spaces in cities are replicating traditional hedges in agricultural areas, forming natural living “borders” between different parts of the urban built environment. The authors make a chilling statement in the article where they describe food as an internationally traded commodity which, by the way, can be eaten. This sums up the dangers and insecurities which have undermined our view of food and has contributed to the disconnect between food producers and consumers.

Consider the illustration below (see Fig. 11) which clearly shows the elements that contribute to food *insecurity*. They can be summarized as follows:

By 2050 - Increased urbanisation (Boisredon, 2019)

By 2050 - Most of the world’s population living in developed countries (Wang, 2018).

The vast amount of food is produced in a rural setting for urban consumption. (Vorley, Lancon, & Frederic, 2016)

The poorest people on the planet spend up to 80% of their income on food whereas the richest people spend 15% (Grey, 2019.)

The Mushroom Garden System addresses all these four issues by designing a food growing system that can work in urban settings at a cost that is commensurate with urban incomes. In order that the world moves from food insecurity to security there needs to be a clear pathway forward, here follows an illustration showing such a path (see Figure 12).

The Mushroom Garden system can play an important part in this journey. The growing system is an ideal vehicle for educating communities as to how to produce food locally. The Mushroom Garden system can easily be incorporated into school or community growing projects. As shown above education is central in the pathway to food security. In addition, the education is intrinsically linked to the actual cultivation and production of the food.

Figure 11: Diagram showing the Urbanisation of the Global food economy redrawn by Jones from the Chicago council.org/globalag, 2020

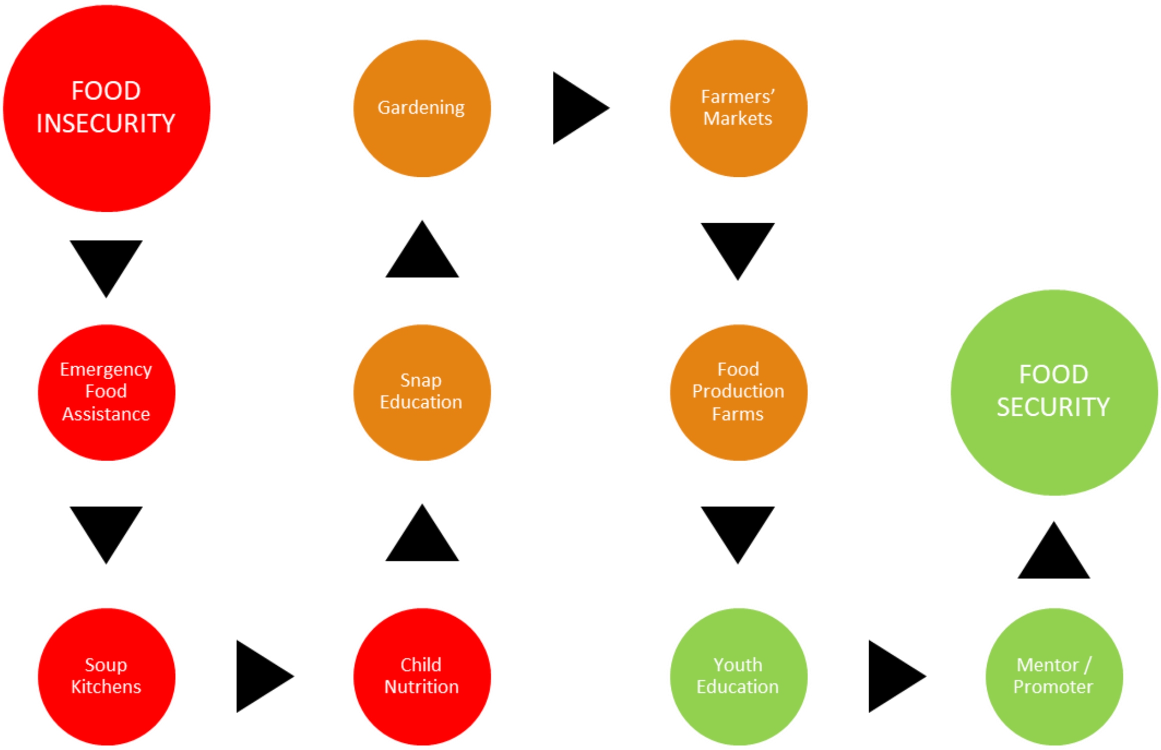


Figure 12: Diagram of a path from Food insecurity to security Cynan Jones redrawn from (Wisdom IAS, 2018)

Definition

Before defining The Circular Economy how it differs from the traditional Linear Economy needs to be considered. This is illustrated below (see **Error! Reference source not found.**)

Figure 13: Linear and Circular economies redrawn by Cynan Jones from Entrepreneurship Campus (Entrepreneurship Campus, 2019)

A **circular economy** is an alternative to a traditional linear **economy.** Most economic models are based on taking finite commodities from the planet to make items which is sold to be used and then when the use is complete or redundant it is disposed of as waste. In a Circular economy we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life. Nick Jefferies

(Jeffries.Nick, 2012) analyses the industrialization of food production and distribution and argues that the current situation is "broken" and unsustainable due to three principal reasons:

The industrial food system contributes to environmental degradation: each year 7.5 million hectares of forests are cut down and 75 billion tonnes of topsoil are lost.

The system is wasteful: on average 30% of all food produced does not make it to the plate, in China 500 million people could be fed by the food that is grown but discarded.

The system is not resilient and does not produce healthy outcomes: the starkest indicator for this is that almost 1 billion people are hungry or undernourished; while at the same time 2.1 billion people are obese or overweight. ((*Prevalence of Obesity*, 2019)

The author then argues that the current system can be addressed by taking four steps:

Four levers towards a circular economy of food:

Close loops of nutrients and other materials: returning nutrients to farms, regenerating soils, directing nutrient flow from wastewater, strengthening soils and reducing reliance on artificial fertilisers.

Cascading value from by-products: recovering valuable chemicals, medicines, and energy, thus providing alternative renewable feedstocks, stimulating the bioeconomy, and eliminating externalities.

Diversity of production: establishing shorter supply chains between farmers and retailers/consumers, reduce the waste associated with transport, creates local jobs, and strengthens resilience as well as urban-rural links.

The power of digital and other enablers: digital allows you to measure, track and locate food and other organic materials with more precision allowing better management and allocation of resources; policy and education are also powerful enablers for steering and empowering.

The diagram below illustrates how a global circular economy could work (see 16)

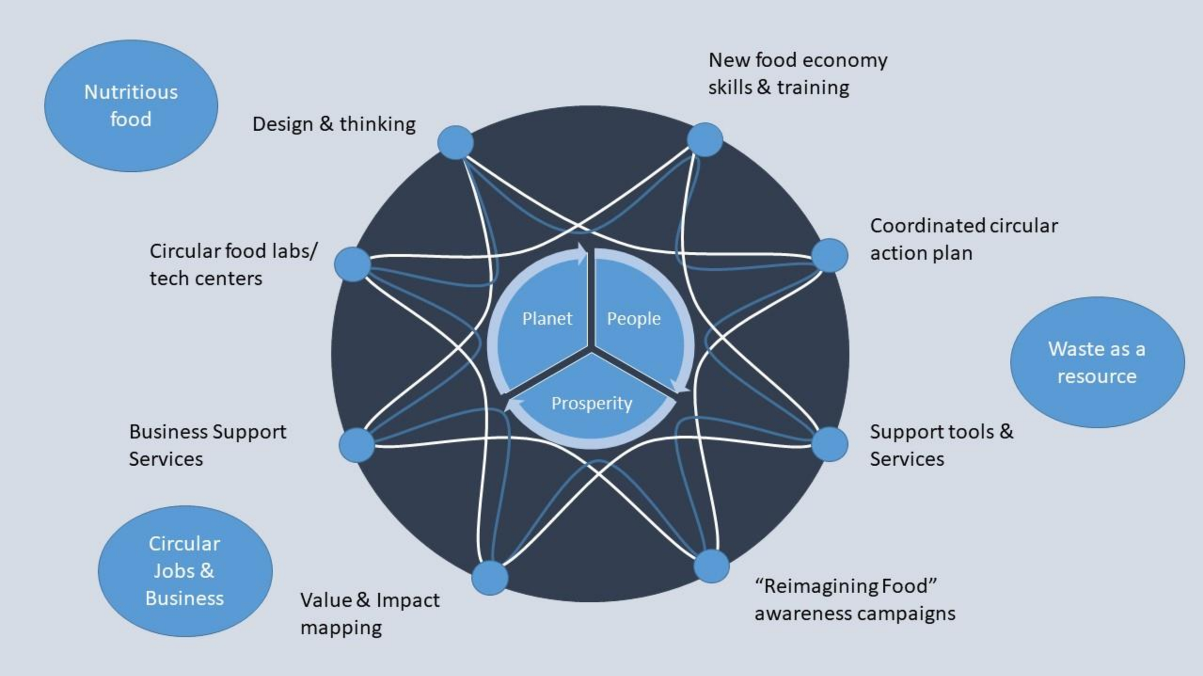


Figure 14: Diagram of the Circular Economy redrawn by Cynan Jones 2020 from Seto (Seto, 2019)

There are many aspects of the Mushroom Garden system that reflect the driving principles of the circular economy: The growing substance is waste wood chip and sawdust used to produce the mushrooms and then the spent substrate is composted. The process thus produces very little waste and no pollution. It is a circular business providing circular opportunities within a local community and keeping as much of the local pound circulating in a very local community and encouraging prosperity. Nutritional food is produced with very low energy input and low waste. The business provides opportunities for new food production skills to be shared within the community and also educates the local population about the means of food production, with low food miles and low carbon footprint.

In a working paper on the Circular Economy a, Michael Søgaard Jørgensen, (Jørgensen, 2019)**,** discusses how the circular economy can play a crucial part in the development of municipal economies. The approach harnesses several elements to achieve a viable circular economy, including social and socio-economic considerations along with environmental and other green considerations. Local procurement by municipalities is a prime example of how the local authorities can contribute directly to the local economy. However, the challenges are many as municipalities do not tend to function as co-ordinated strategic organizations which results in disjointed policies and operations. The Mushroom Garden system can provide a workable system to present to municipalities as a template for coordinated planning from collection of substrates from parks to assistance with distribution.

3.2 THE FOUNDATIONAL ECONOMY

The Welsh Government has commissioned a large body of work on the Foundational Economy as it believes that it should be the basis of Welsh economic policy.(Miller, 2017) The definition here of a foundational economy is from a presentation to Welsh Government civil servants in 2018 by the authors of a published collection of papers under the title 'Foundational Economy 2018'(Government, 2018)There follows two complementary views on what a Foundational Economy is or should be:

'The foundational economy is about collective consumption through networks and branches which are the infrastructure of civilised everyday life. The foundational includes the material infrastructure of pipes and cables which connect households plus providential services like health and care which citizens rely on; outside the foundational, there is a mundane overlooked economy of haircuts and takeaways.

The foundational economy is about universal basic services which are a citizen entitlement and it is therefore about politics as much as economics. From a foundational view point, the distinctive role of public policy is not to boost private consumption by delivering economic growth but to ensure the quantity and quality of foundational services.'(Government, 2018)

These above statements come from a web-site which has been established and managed by a network of academic researchers and community development practitioners and activists (Williams, 2020). The premise underpinning the concept of The Foundational Economy is social justice, where individual needs drive the local economy to encourage prosperity (in its widest possible sense) and security, rather than exploitative growth. The Foundational Economy has a strong base of academic research to back up the concept (Williams, 2019) Led by Professor Karel Williams at Manchester University, Professor Williams has, in partnership with The Open University, established CRESC, the Centre for Research on Socio Cultural Change, which actively supports community based research in a participative way. One such programme is the work being carried on with the social enterprise Dolan in Northwest Wales.

DOLAN is a joint venture between community groups and social enterprises in three deindustrialized North Wales Valleys which were formerly major centres for slate mining. These are Cwmni Bro Ffestiniog in Blaenau Ffestiniog, Partneriaeth Ogwen, based at Bethesda and Yr Orsaf (Siop Griffiths) in Penygroes and the Nantlle Valley. The Bro Ffestiniog federation of social enterprises in one of the valleys has a community broadcast arm which has produced a short video which explains what the Foundational Economy means to them (Dolan, 2021). The film mentions that food production is an essential element of the Foundational Economy and explains how adopting a community-based approach to servicing our basic needs is crucial to creating a vibrant and healthy community economically, socially and culturally. Figure 15 below illustrates how the Foundational Economy is built on the requirements and needs of the community. The Mushroom Garden system is designed to function within the Foundational Economy in terms of local, community-based, nutritious food production as a foundational need.

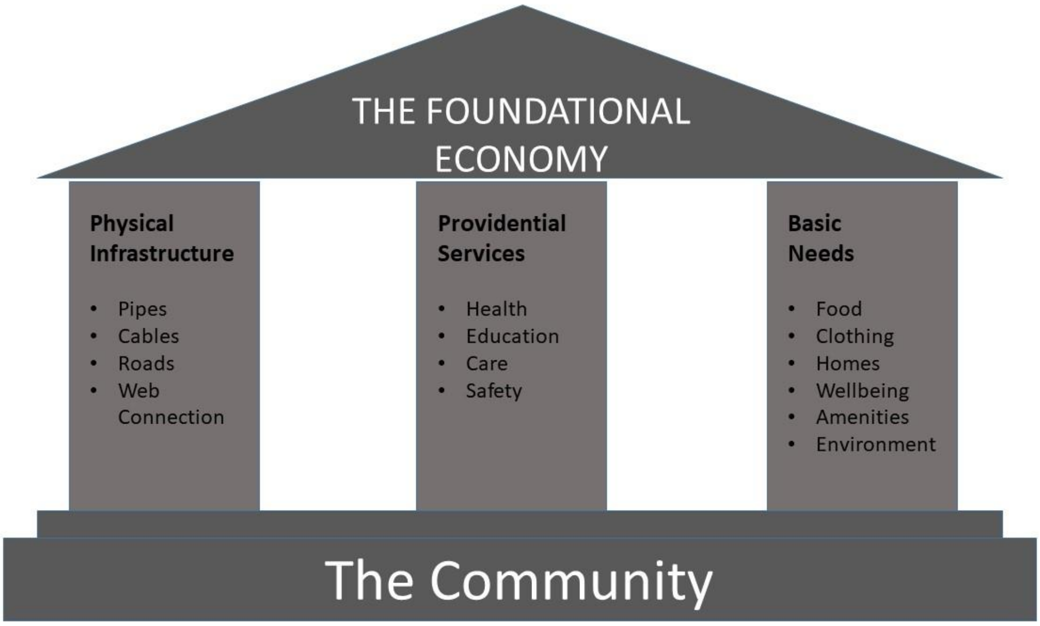


Figure 15: The Foundational Economy (Jones, 2021)

3.3 Post Anthropocene

Before the Post-Anthropocene is discussed, it is important to understand what the term means, and how the planet and society has arrived at this phase in its development. Since the industrial revolution, the world has been in the Anthropocene epoch (although the Anthropocene is not recognised as a true geological epoch it is widely used when discussing the state of the planet's health). This is the time when humans have had a direct effect on the planet's environment. This has manifested itself in two major ways - global warming and pollution of land, sea and air. In her book, *Adventures in the Anthropocene*, Gaia Vince (Vince, 2014) takes us on a planet wide journey describing and analysing how humans have taken ownership of the Earth and its resources, lands, seas and atmosphere for their own benefit. This has happened to the detriment of the planet and its life forms and depleting natural resources and influencing many of the planet's natural systems from sea levels to air quality to global temperatures. Although presenting quite a dark outlook initially, she believes, however, that it is not too late to change things and discusses the changes in human behaviour and politics that are needed to avoid disaster.

A complementary concept to the Post -Anthropocene is that of Planetary Boundaries. The concept of 'Planetary Boundaries', as introduced in 2009, aimed at defining the environmental limits which would keep the planet hospitable for modern human life. These are not geographical boundaries but rather virtual boundaries that describe human economic and behavioural activities that can reach limits which adversely affect the planet's ecosystem. These are essentially the preconditions for human development. This new approach was provided by scientist and sustainability expert, Johan Rockström (Rockstrom 2006.). Planetary Boundaries create a set of conditions that provide a framework for successful human development in harmony with environmental and geophysical systems. The boundaries are delicately interlinked and crossing them is an indication of irreversible damage to the planet.

There are generally accepted boundaries:

1. Climate change

2. Rate of biodiversity loss (terrestrial and marine)

3. Interference with nitrogen/phosphorus cycles

4. Stratospheric ozone depletion

5. Ocean acidification

6. Global freshwater use

7. Change in land use

8. Chemical pollution

9. Atmospheric aerosol loading

The analysis argues that the 11,700-year Holocene period has seen the comparatively rapid development of human life, civilisations and agricultural and economic systems on the planet leading to the boundaries being approached and, in some cases, crossed making modern life unsustainable, which can spell disaster for humanity and end the Earth. It is from this background that the word Anthropocene was coined to describe an epoch where humans had been able to manipulate and change the earth's ecosystems (Pavid, 2020). As mentioned above(Rockstrom, n.d.), the Anthropocene is not sustainable and scientists, environmentalists and political activists have been looking to what happens next, where is the Earth and humankind going and it is this development that has led to the Post-Anthropocene to think as to what sort of planet and humanity can emerge from the Anthropocene. Many scientists now believe that we are at a tipping point as to where the planet is heading in the next phase and the following diagram illustrates four plausible futures (see Figure 16).

In Figure 16 the two axes divide the world into four plausible futures, the vertical axis relates to planetary health and the horizontal relates to societal conditions. Four quadrants illustrate the four futures. One of the outcomes, is **Post Anthropocene**, which will be discussed with the other scenarios:

Greentocracy- This future will have planetary health as its primary aim, with societal condition virtually ignored, leading to a much-improved planetary environment but a breakdown of society and economies.

Extinction Express - in this scenario both societal conditions and planetary health are declining leading to mass extinction of species and eventually humanity itself.

Humans PLC - In this scenario planetary health has declined but societal conditions have improved. That is human needs and wants to have taken over all other activities, especially planetary health, leading to a decline in environmental systems and processes that benefit the planet.

All the three futures described plausible futures that are non-sustainable in the long term the final scenario is **Post Anthropocene**.

From the diagram below, the Post Anthropocene scenario is characterized by two conditions:

Planetary health improves.

Societal condition improves.

The Post Anthropocene can be described as *Utopia*, or a state of perfection benefitting life on Earth, the environment, and a sustainable global economy. In this scenario the world of 2050 boasts a balanced biosphere, where humanity and planet earth coexist in harmony, the best possible outcome for the future. Among the four scenarios a Post Anthropocene scenario is the most ideal. It is the scenario where humans are in harmony and the world is in a regenerative phase. Such ideal scenarios rarely materialise fully, unfortunately. However, it is important to investigate such an outcome as a way to align our policies in actions. To arrive at this outcome or even to get close to such a Utopian planet many factors need to change in terms of society, economics and environmental strategies. A contributory factor to fashioning the Post Anthropocene is to "communitise" economies and specifically food production. Such steps will increase nourishment, reduce food miles, and create a more secure food environment.

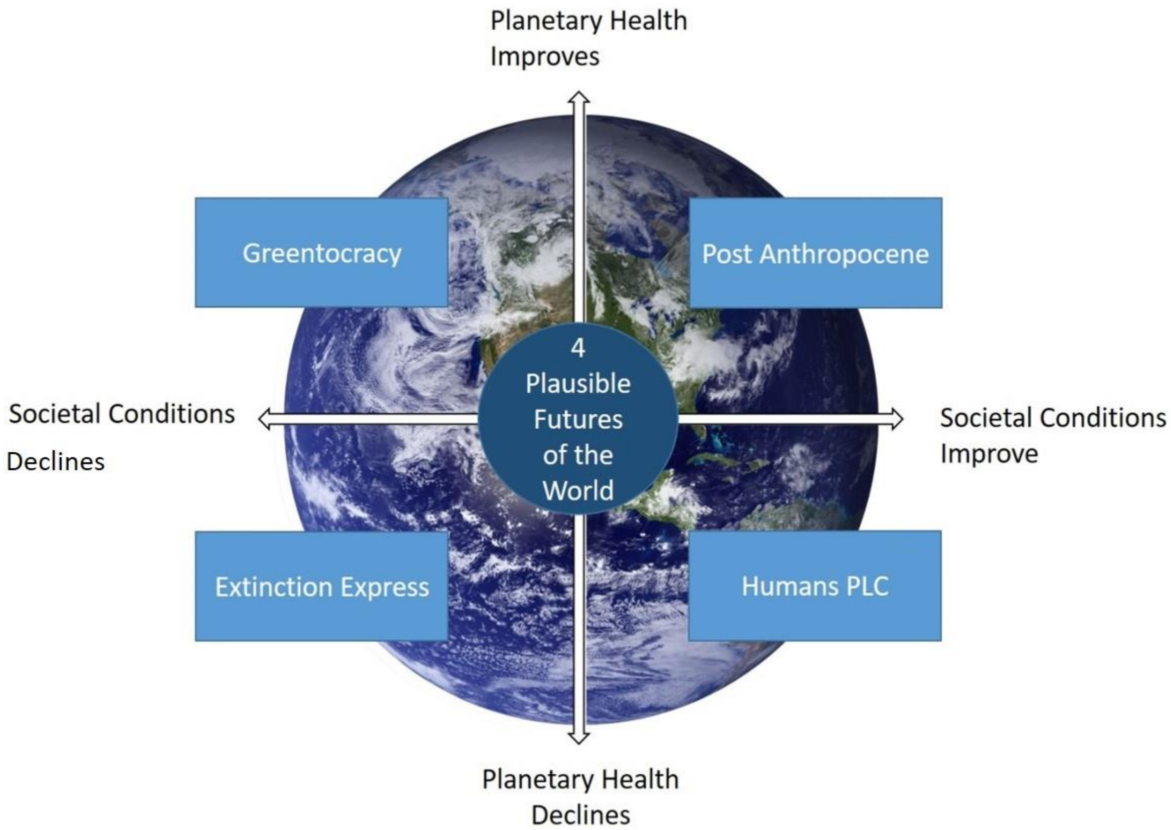


Figure 16: redrawn by Jones from Arup report Possible World Futures 2050 (Arup, 2019)

The Mushroom Garden system, alongside other community-based food growing projects, can play an integral part in an urban setting to bring food production closer to the consumers and to integrate food production spaces with living spaces. **Post-Anthropocene** is only one of the four scenarios that the world will end up being in by the year 2050. We have also established that this scenario is the most ideal one, characterized by a healthy society and a healthy planet. Setting this scenario as an aim for the planet is important as a means of educating humans and their systems. However, action is needed in addition to policy changes on both a geopolitical and a community level. This dissertation makes the case for local initiatives in food production can inform to a global audience to face these planetary challenges.

4 METHODOLOGY

4.1 FULL SCALE PROTOTYPING

The work is a practice-led research where the main investigator is the farmer himself, a *First person practitioner* (Sevaldson, 2005). Addressing today's most burning questions of food security, social, natural and economical sustainability, inequality and scarcity, the author believes that the research has a strong potential both, globally, as well as locally, with a local-specific agro-architectural application for the Post-Anthropocene cities. The **objective** of this research is to explore how a relatively simple bio-technological, modular, energy-efficient system for growing high-quality, nutritious mushrooms can contribute to and address challenges in global food production and distribution systems. Framing this objective are again the five fields of relevance to the growing system and its application, namely:

Sustainable food production

Food security

The Circular economy

The Foundational economy

Post-Anthropocene.

In parallel to investigating how the application of the growing system has relevance to the above five fields, the system itself has been monitored and refined to improve energy and productivity efficiency. This bilateral approach involves gathering and analysing both hard data i.e., actual measurements from the growing room and the mushrooms. Soft data was also collected and analysed. This involved looking at how the system can be applied to different settings and how individuals interact with the system at various levels as workers, consumers, and members of the local communities where the system is located. In many community-based enterprises the soft facts and social impacts are crucially important to get community 'buy-in' to the project and therefore to increase the long-term sustainability of a project. e.g. Social Return on Investment research project in Gloucester(Baker et al., 2017) The research projects cited above place a monetary value on the changes-for-the-better in the lives of individuals involved in community-based food growing projects. The results show that 62% of those involved in the projects reported improvements in health and wellbeing, a 26% increase in community vibrancy and 8% improvements in education and skills. This translated to a value of between £6 and £8 returned for every pound invested in the project.

4.2 SYSTEMIC DESIGN

Systems Orientated Design is a way of exploring possibilities by simultaneously exploring design-thinking and practice with systems-thinking and practice. The approach was proposed by Birger Sevaldson (Sevaldson, 2013). In this dissertation the systemic design approach has been useful when describing and analysing the growing system while exploring the various technical and design elements of the process. The Mushroom Garden's growing system is based on fine tuning and controlling the environment within an enclosed area where the key elements to securing consistent yields and quality of the product can be managed in an energy efficient way. To that aim, equipment was used to monitor temperature, humidity, and energy input under two lighting regimes - fluorescent lighting and LED of the same quality. The manipulation of the variables in the growing process, i.e., temperature, light, humidity, and air-circulation demand a systemic design approach which integrates the human experiences of growing on a practical day-to-day level with the design techniques to maximize efficiency in the growing process.

4.3 Research by Design in a REAL-LIFE Laboratory.

The work also uses a co-designing approach with the practitioner gaining experience through living and working with the system being designed. Davidova *et al*. (Davidova, 2020) employs this approach in architecture and shows how multi-disciplined and-real time co-working leads to a dynamic, and results of the whole being much bigger than the parts. The workplace is therefore the full-scale prototype and laboratory where the research is undertaken. Experimenting with the growing conditions, collecting data and adjusting the environment happens organically as part of the day to day working of the business (Davidova, Marie; Panek,Karel; Pankova, 2018). The original prototype ids the first case study in this research. Two other case studies were then developed (The Battlesteads Hotel and the Awen Cultural Trust - see chapter 8) based on the data and practice from the first prototype and adapted to suit the two new applications.

4.4 Hard Data Measurements.

All the data captured during the research was gathered in the full-scale prototype growing unit which is described below. The temperature and humidity were measured using Tiny Tag sensors and probes (See Appendix 1).

4.4.1 The Environment Created.

As noted above the basic requirement for a growing room is an insulated box that can be cleaned thoroughly, where temperature, air quality and humidity can be controlled, and light timed on and off. This can be achieved using shipping containers, second hand 'refer' units from food transport lorries or insulated poly-tunnels. All the equipment, (humidistat, centrefugal blowers, air filters, heaters, lighting, and shelving and misting system) are standard. The water supply has to have sufficient pressure to allow for misting and the electricity supply is single phase. The light source was changed during the data collecting period from fluorescent initially to LED, and this research confirms that LED light is preferable in the growing rooms.

4.4.2 Optimum conditions.

This researched has monitored the following:

Distribution of temperature within growing room

Distribution of Relative Humidity within growing room

Internal block temperature

External temperature

Yield of mushrooms (weight)

Distribution of light strength within growing rooms.

Each process for monitoring is described below:

4.4.3 Distribution of temperature within growing room

Three Tiny Tag monitors were placed in the growing room at the following locations:

Lower shelf front

Middle shelf Middle

Top Shelf back

4.4.4 Distribution of Relative Humidity within growing room

Three Tiny Tag monitors were placed in the growing room at the following locations:

Lower shelf front

Middle shelf Middle

Top Shelf back

4.4.5 Internal block temperature

Tiny Tag with probes.

4.4.6 External temperature

4.4.7 Weather station sited in vicinity of the growing room.

4.4.8 Yield of mushrooms (weight)

Weight of harvested mushrooms taken from sample of blocks (10) under both fluorescent and LED lights.

4.4.9 Distribution of light strength within growing rooms

Measured at three locations within growing room, Front of container top shelf, Middle of container middle shelf and back of container lower shelf.

4.4.10 Nutritional values of Shiitake mushrooms

Measured under both Fluorescent and LED lights.

4.4.11 Vitamin D content

Measured under fluorescent and LED lights.

5 The Full-Scale Prototype

5.1 How the Mushroom System works

Growing exotic mushrooms using the Mushroom Garden system is intended to be an income supplement to individuals, small businesses, farms, and social enterprises. It is an activity that can be planned around other jobs in the business or enterprise, with the added benefit of generating an all-year-round predictable income. That said, growing is a task that involves several technical requirements such as maintenance of hygiene regimes and control of conditions to ensure the predictable income part of the equation. These requirements are different from many standard businesses or even growing activities. The Key challenges that have been successfully overcome are:

The need to maintain a constant and consistent growing environment.

Maintaining strict hygiene standards and practices in a potentially non-hygienic environment.

Presenting the product well, so that maximum added value benefit is achieved at point of sale.

In broad terms, the essential elements of the production system are: -

Spawn production

Block production, including sterilization and inoculation.

Incubation

Growing rooms

Harvesting

Inspection

For the purposes of this project the focus will be on the growing, harvesting and inspection of the mushrooms since the initial stages of spawn production, block production and incubation are carried out at other sites. However, the whole process is described below so that growing is seen in context of the complete process.

5.2 Mushroom spawn

Mushroom culture is available commercially but requires the skills of a trained mycologist or microbiologist to isolate and maintain growing strains. They are also needed to convert this to the initial seeding medium (grain spawn) that is added to each block to initiate the process. The Mushroom Garden has the facilities to produce the grain spawn and to inoculate the growing substrate.

5.3 Production Arrangements

Commercial mushroom production is carried out in a highly controlled environment (temperature, humidity & hygiene) and can therefore take place all year round. This means there are no seasonal supply-limiting factors and growers have better control of their production. Although there are several options available as to the type of unit utilised, The Mushroom Garden system uses specially equipped international-standard 20 ft. shipping containers or insulated second-hand lorry, with the fridge or chiller unit removed, refrigerated units as the two controlled operating areas in the process. Facilities should include separate incubation and growing rooms. The ground needs to be solid – e.g., built onto stone or concrete yard. The containers must slope (2-4 inches) from back to front so that water can drain from the front of the container. A water and electricity supply (3KW for growing rooms and incubation rooms) is essential and must be available on the premises. Good quality containers are used to provide structural integrity and a suitable life for the facility.

In general, they need to be:

Lined with washable plastic sheets to make them hygienic.

Racked out to provide suitable support for incubating or growing mushroom blocks.

Air is filtered into them.

Flow and volume of air is managed.

Equipped with light, heat, and water.

The production challenge is to maximize yields of premium grade mushrooms to achieve premium market prices whilst using the minimal inputs to produce the crop.

5.4 MUSHROOM GROWING PROCESS OVERVIEW

The flow chart above (see Figure 17) illustrates the Shiitake and Oyster mushroom growing process which is described in detail below. The rationale for establishing this type of facility is as follows. Mushrooms such as Shitake and Oyster are grown commercially in many parts of the world, but specifically in the far East by allowing a mycelium to develop throughout a felled tree or log. This takes considerable time as significant mycelium development only occurs when certain climatic conditions apply. Fruiting then occurs when the mycelium runs out of nutrient or is stressed in some way. At this point, the mushroom is developed and when the log is shocked by sudden changes in the ambient climatic conditions, the reproductive body of the mushroom is produced to ensure the survival of the organism. Our mushrooms are not grown on logs but on a specially prepared growth medium - wood chip and sawdust for Shiitake and Straw for Oysters. This accelerates the growing process, makes yields more predictable and increases the rate of return. The sequence for the whole process for Shiitake is as follows:

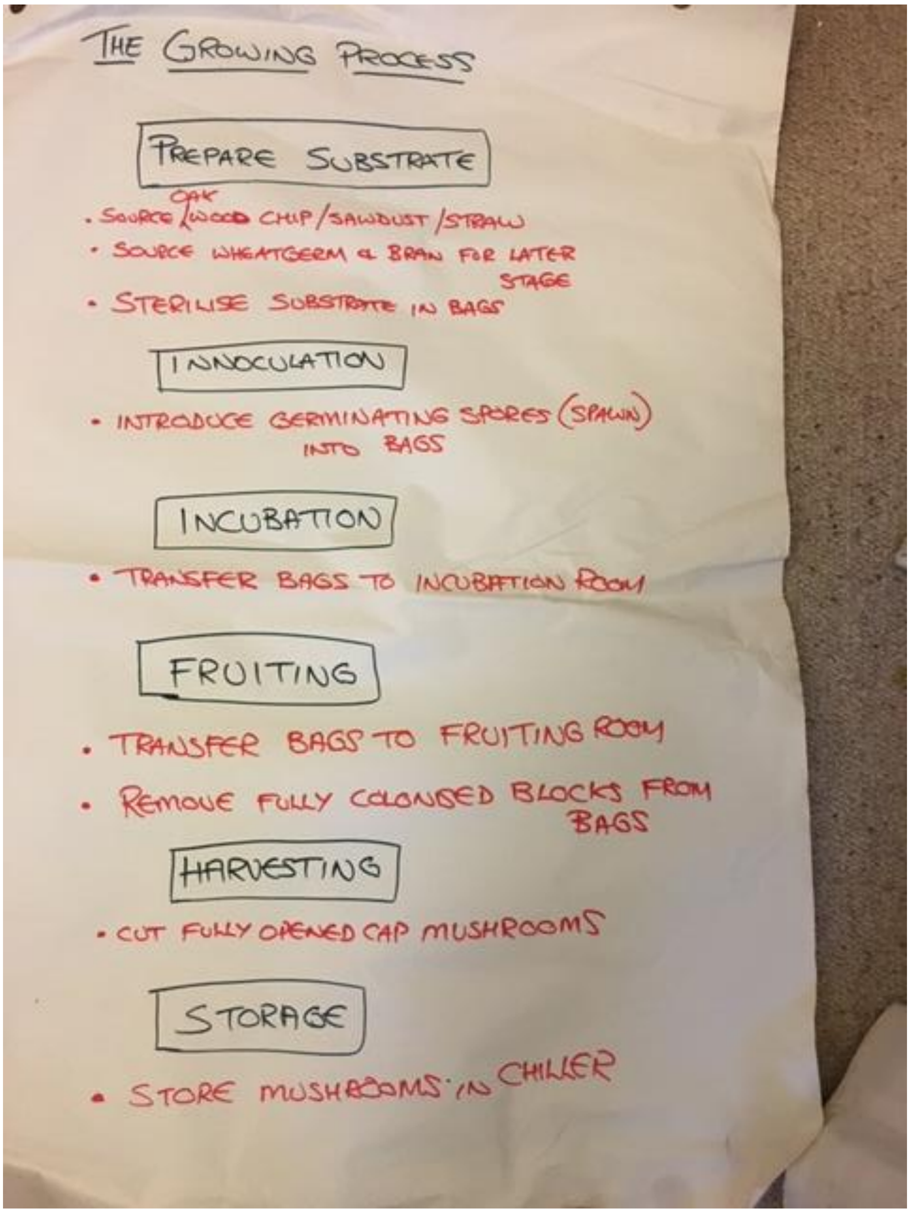


Figure 17: The Mushroom Growing Process (Jones, 2021)

5.4.1 Substrate preparation

Prepare growth medium for the fungus by chipping oak wood with a mixture of bran and gypsum.

Commercial Sterilization is accomplished by retorting the growth medium into specially produced, heat resistant plastic bags (see Figure 18). This is allowed to cool down before adding the strain.

A specific strain (in the form of grain spawn) of mushroom is added to each bag under controlled conditions to produce the correct end-product.

Commercial Sterilisation has reduced competition from other species and allows the desired monoculture to develop.

Block production ends here, and blocks, (at this stage bags of growing medium) are transferred to the incubating room.

The process for Oyster mushrooms is very similar, but the main constituent of the substrate is straw.

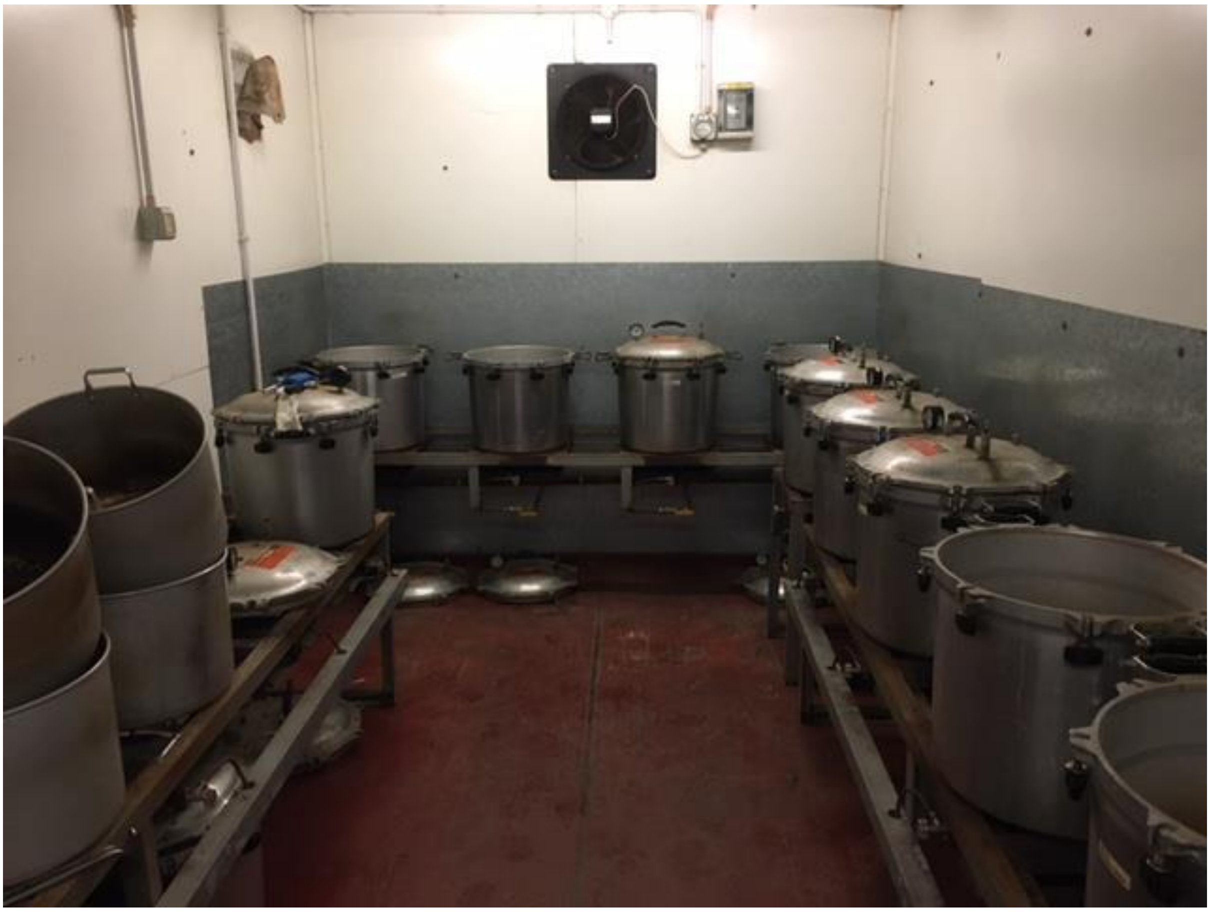


Figure 18: Substrate Sterilizing Room (Photo: Jones, 2021)

5.4.2 Incubation

Clean incubation rooms are the key to successful blocks. Pre-incubation, they are vulnerable to contamination until a good growth of mycelium is established and even then, can be compromised by other more virulent organisms. The rooms are prepared and then cleaned at regular intervals according to an established cleaning regime as described below:

The incubating rooms are very dry, (see Figure 19) therefore there is little moisture for rapid fungal or bacterial growth on the shelves, ceiling, floor, or walls. However, the rooms do become very dusty.

On a monthly basis all shelves and surfaces should be wiped down with a damp cloth using a solution of organically acceptable cleaning material – the Mushroom Garden uses solutions acceptable to the Soil Association.

Incubation rooms are heated to between 19-23ºC. Blocks are placed on to racks and kept in batch lots so that inspection records can be kept and fruiting readily spotted. Records are kept of when blocks arrive and regular checks (at least every two days) are made to ensure that blocks are free from contamination. (Green mould, usually strains of *Trichoderma or Penicillium*). If these traces are found the blocks should be removed from the incubating room immediately and disposed of.

During the incubation period the blocks change progressively from a soft white block, into a solid brown block, which generally indicates complete colonisation of the block showing that good fruiting is ready to occur. A key sign that fruiting blocks are ready to be removed from the incubation room is when the grower can clearly see cracks forming in the crust of the block.

Figure 19: Incubating room (Photo: Jones, 2021)

So now blocks are removed from the incubation room (See Figure 18) when these signs appear. Generally fruiting blocks take between 8-10 weeks before they are ready to produce mushrooms. However, sometimes blocks try to fruit as early as four weeks after being made – hence regular inspections of fruiting blocks in an incubation room is essential and takes only a short time during the working day for an experienced grower. Some blocks may begin to produce mushrooms at the 'white-stage' but, again, there should be no problems providing that the grower is monitoring the blocks regularly. Some growers wait until two mushrooms are pressing against the bag before placing blocks into the growing room. When the blocks are ready to fruit, they are removed from the incubation room and taken into the growing room (see Figure 20).

Figure 20: Growing Units (Photo: Jones, 2021)

5.4.3 The Growing Rooms and Transfer to Grow Room.

This is the point at which the blocks are shocked, to produce fruiting bodies, giving us the mushrooms, we can harvest. It is best to remove the blocks, which are seen as being ready to fruit from the incubation room in one movement. The most effective way to do this is to enter the incubation room, ensuring that the door is closed following entry, arrange the blocks so that the ones, which are closest to fruit are placed next to the door. Once the bags are outside the incubation room, the grower needs to remove the bags and place the blocks into the grow room. When bags are opened, they can make a mess and opening in the grow room can result in substantial water being spilt on the floor (which has to be cleaned up by hosing out). Having the door open for 30-40 minutes is acceptable.

A simple acceptable sequence of events might be:

Open incubation room. (40 minutes max)

Transfer blocks to external working table

Remove bag (see **Error! Reference source not found.**)

Remove plastic covering (see Fig 21)

Transfer “naked block” to second working table or trolley

Move to grow room.

Stack on shelves (see Figure 24)

Disposal of the residual bag must be made in accordance with the Agricultural Waste Regulations 2006. Further guidance can be obtained from the Environment Agency.

Figure 21: Growing block arriving at growing room (Photo: Jones, 2021)

Figure 22: Opening the Growing block (Photo: Jones, 2021)

Figure 23: Removing the plastic covering (Photo: Jones, 2021)

Figure 24: Placing the blocks on shelves in the growing room (Photo: Jones, 2021)

5.4.4 Fruiting in the Grow Room.

This is the point at which the blocks, now free of their bag, are placed in an environment conducive to producing significant quantities of mushrooms we can harvest. When blocks are placed on to shelves in the grow room, they will begin to produce mushrooms. This becomes obvious within 2-3 days of being stacked onto the shelf, providing that the conditions for growing are suitable. Optimum conditions are humidity between 90-95% and the temperature between 12-15 degrees C. The air is changed in the growing room every hour to avoid build-up of CO_2 which can impair mushroom cap formation (see Figure 25).

Figure 25: the growing room fully stocked (Photo: Jones, 2021)

5.4.5 Harvesting

The grow room needs to be monitored constantly to harvest the mushrooms when they are at their peak. It is best to wait until the cap is nearly unfurled before cutting, which is done with a pair of scissors. This stage can be pinpointed as just before the cap has completely opened and when there is a small rim on the mushroom. They need to be cut off flush to the surface of the block, as green mould can appear if stumps are left on the block. The stalks are sold on the mushroom. If mushrooms are left on the block for too long so that the cap is allowed to flatten out, then spores will be released, and this will gather in the room – particularly around the fan/blower. This should be cleaned with a damp cloth if this happens. Mushrooms may not all be ready to harvest from a block at the same time – some grow faster than others – so the grower must decide whether to harvest all at once, including the smaller mushrooms, or to remove some mushrooms from a block and then go back to it the following day. Demand dictates action. (See **Error! Reference source not found.** and 2 8) When the grower has removed all mushrooms from a block, the block then needs to be removed from the grow room and stored in a dry place. (See figure 26).

Figure 26: Shiitake blocks fruiting (Photo: Jones, 2021)

5.4.6 Second Flush

At this point fruiting blocks are removed from the first growing environment. The blocks, once removed from the growing room, are retained on site in a dry well aired environment and second-third flushes would be added to the mushroom yield as they occur, thereby increasing the profitability of the enterprise. The area chosen for second and third flush fruiting needs to be dry and must allow reasonable airflow (open window or air-vent); heat and humidity are not as important as the first-flush stage. Fruiting blocks can be fruited again after a week or so of drying, which growers recommend in order that the mycelium has sufficient time to recover from the stress of fruiting - keeping them for longer is not a problem, providing that they are kept dry (indoors).

The strategy followed generally, is to allow the blocks to dry, and then to soak them in a water tank (water trough, water-butt, etc.) for between 10-24 hours. If blocks seem impermeable, piercing several holes into the block will help water uptake. Growers need to experiment because the blocks will absorb different levels of water at different times of the year. If the blocks absorb too much water and are placed into a room that is too cold, then there is a risk of contamination and green mould may appear. However, airflow is crucial here, so doors or windows may need to be kept open at certain times of the day. The intention with the second-flush blocks is to keep the costs (and energy input) to an absolute minimum. There are only two fundamental considerations here:

The blocks need to recover from the stress of the first flush and this is done by allowing them to rest in a fairly dry room – poly-tunnels have been used as have sheds of all descriptions, in fact anywhere that is waterproof and allows for good air movement will be sufficient.

Organisation and effort will help to get the blocks to fruit, yielding good quality mushrooms.

Multiple flushes may be obtained by following the same sequence of events described to initiate a second flush.

5.5 Critical Control Points

The production of foods requires that the producer has a HACCP plan which identifies critical points in the production process (See below) Hazard Analysis and Critical Control Point (HACCP) stipulates how to manage the food hygiene and safety procedures in a food business. HACCP is a way of managing food safety hazards.

CONTROLLED DOCUMENT No. YAF-300	ISSUE No. 02 BY: CJ	**The Mushroom Garden HACCP PLAN**	

BUSINESS NAME: YR ARDD FADARCH / THE MUSHROOM GARDEN
CONTACT DETAILS: Glan Meirion, Nantmor, Caernarfon, Gwynedd, LL55 4YG Tel: 01766 890353 www.themushroomgarden.com cynan@themushroomgarden.com
HACCP STUDY FOR: Fresh Mushrooms
DATE OF PREPARATION: April 2020
REVIEW DATE: April 2021

5.5.1 HACCP TEAM:

TEAM MEMBERS	JOB TITLE	HACCP EXPERIENCE / QUALIFICATIONS
Cynan Jones	Director/Team Leader	Open college network HACCP certificate
June Jones	Director	Internal training

5.5.2 HACCP SCOPE

This HACCP considers the hazards involved, and implements control procedures and monitoring for producing the following products:

Fresh Mushrooms: Shiitake & Oyster

1. FRESH MUSHROOMS: SHIITAKE & OYSTER	The HACCP plan covers all steps from the receipt of inoculated growing blocks to the dispatch (or further processing – see Products 2-6 above) of the fresh mushrooms
Microbiological Hazards:	• Potential infection with moulds such as *Trachyderma* and *Penicillium* on growing substrate • Potential process cross contamination from growing room or operator
Physical Hazards:	Potential contamination from environment, operator, cleaning equipment and packaging, e.g., insects, soil, wood chips, debris, hairs etc.
Chemical Hazards:	Potential contamination from incorrect cleaning agents, insufficient rinsing and incorrect dilutions of chemicals, pesticides, non-food-grade packaging
Allergenic Hazards:	None
Intended Use:	Either sold as fresh mushrooms for customer use (eaten raw or more commonly cooked as part of a meal) or are mostly processed into mushroom products
Process Details & Parameters:	▪ Shitake blocks collected from supplier and grown under controlled conditions in Incubating Room 1 & Growing Room 2. ▪ Oyster blocks delivered to pick-up point, stored in chiller until ready to enter Growing Room 2. ▪ Incubating Room 1 conditions are maintained at 25°C ± 5°C. Growing blocks are all within sealed bags in this room. Temperature control is an efficiency/growth rate issue and not a food safety issue. ▪ Growing Rooms 2 and 3 conditions are maintained at 15°C ± 5°C and 97% ± 5% RH. Blocks are exposed in these rooms for the mushrooms to grow. Bags are removed by ripping off by hand or sometimes using scissors. Temperature and

	humidity control is an efficiency/growth rate issue and not a food safety issue. ▪ Harvesting – mushrooms picked by gloved hands, sometimes using scissors, into plastic trays. ▪ Harvested blocks left to re-grow in either Room 2 or Room 3 and re-harvested within 2 weeks, with each block typically harvested at least 3 times. ▪ Blocks composted on completion of growing cycles. ▪ Harvested mushrooms stored in on-site chiller at 3-5°C, in lidded plastic containers, until all are harvested. ▪ Mushrooms transported to Processing Room in same plastic containers (5 mins by car), usually same day. ▪ Storage in chiller at 3-5°C ▪ Pack into boxes ▪ Storage in chiller at 3-5°C ▪ Dispatch (usually that afternoon following harvesting) OR used for products 2-6, as above
Packaging:	Fresh mushrooms are sold loose in cardboard boxes
Weight:	1kg and 2kg boxes
Storage & Distribution:	The packed mushrooms are stored in boxes in the chiller within the processing room. These are placed in sealed plastic containers for transportation by car or courier. Delivery by car is max 20 mins. Delivery by courier is maximum next morning delivery.
Potential Customers:	The fresh mushrooms are dispatched directly to hotels, restaurants and delis. They are suitable for consumption by all members of the population including the young, elderly, infirm, vegetarians and vegans.
Shelf Life / Conditions of Use:	7 days in chiller.

5.5.3 RISK ASSESSMENT OF HAZARDS

Each hazard identified in the HACCP plan is risk assessed using the following scoring system. This assesses both the likelihood of the hazard occurring and its potential severity or impact on health.

SCORING FOR SIGNIFICANCE	
Likelihood or Risk:	**Severity or Impact on Health:**
1 = Unlikely to Happen	1 = No health impact / quality issue only
2 = Could Happen	2 = Minor / reversible injury e.g. broke a tooth
3 = Has Happened / Likely to Happen	3 = Serious injury or illness, may cause death

The score for likelihood is then multiplied by the score for Severity, as follows:

DECIDING ON SIGNIFICANT HAZARDS		**Severity or Impact on Health:**		
		1	2	3
Likelihood / Risk:	1	1	2	3
	2	2	4	6
	3	3	6	9

For those hazards then deemed ‘significant’, suitable measures must be identified for the control of the hazard.

5.5.4 Determination of criticality

Once all the hazards have been identified and risk-assessed for likelihood of occurrence and the severity to health, the following CODEX Decision tree is then used to determine whether a process step is a Critical Control Point.

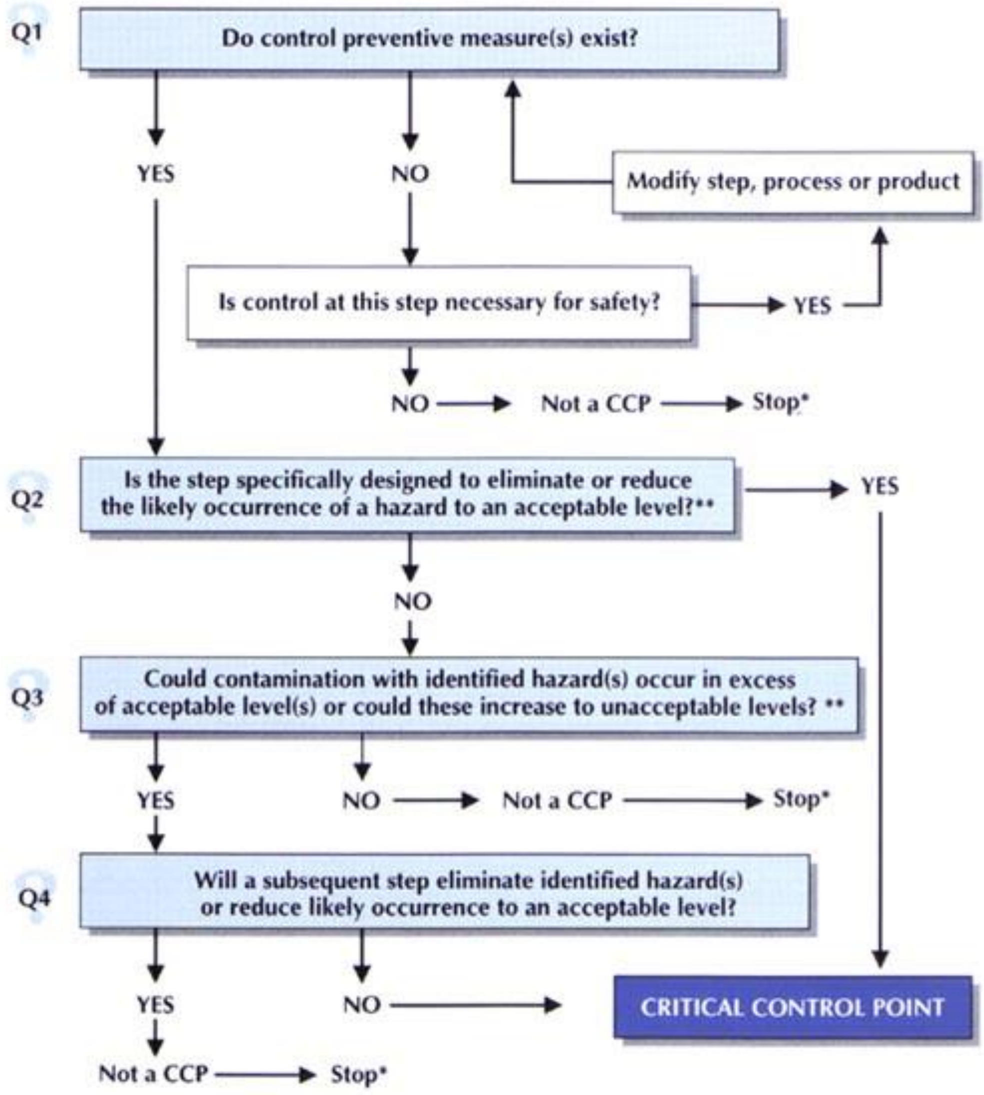
Pre-requisites – These are key operating procedures which support the HACCP plan (e.g., cleaning schedules, pest control policy, hygiene policy)

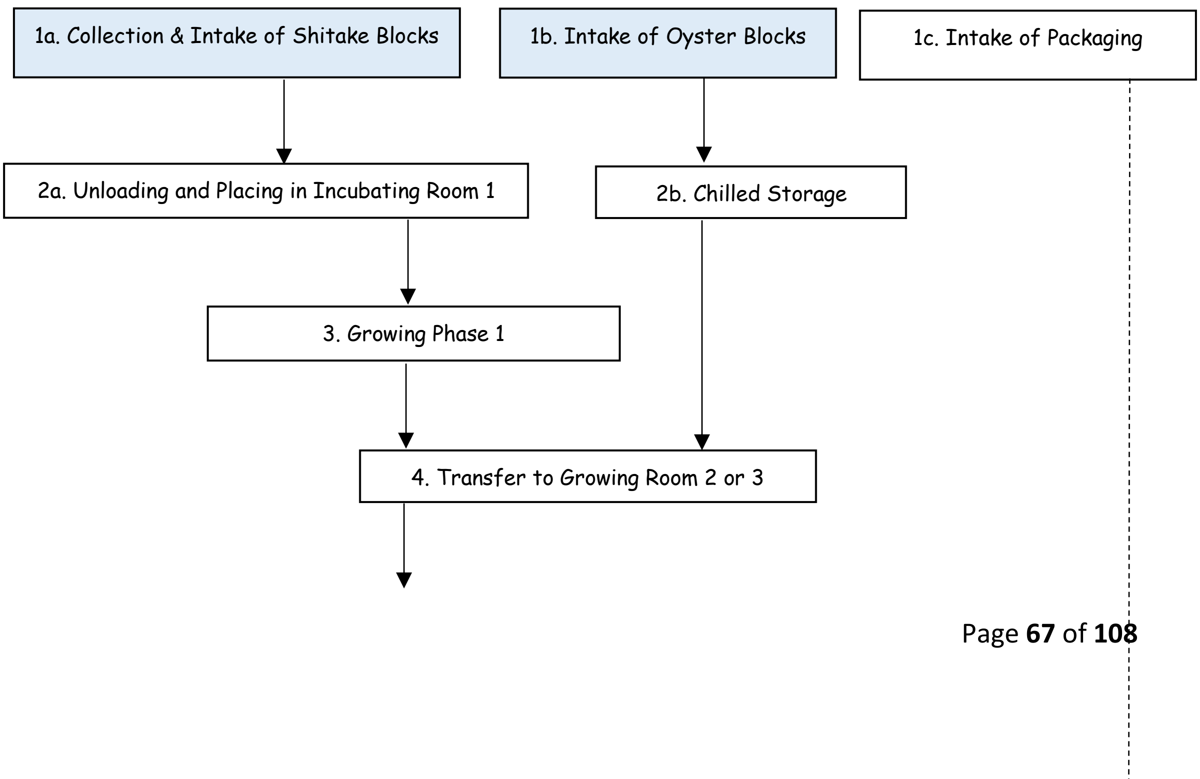
Good Manufacturing Practice (GMP) – Activities covered by the pre-requisite procedures which support the HACCP plan are considered standard operating practice, for which the appropriate staff members are trained.

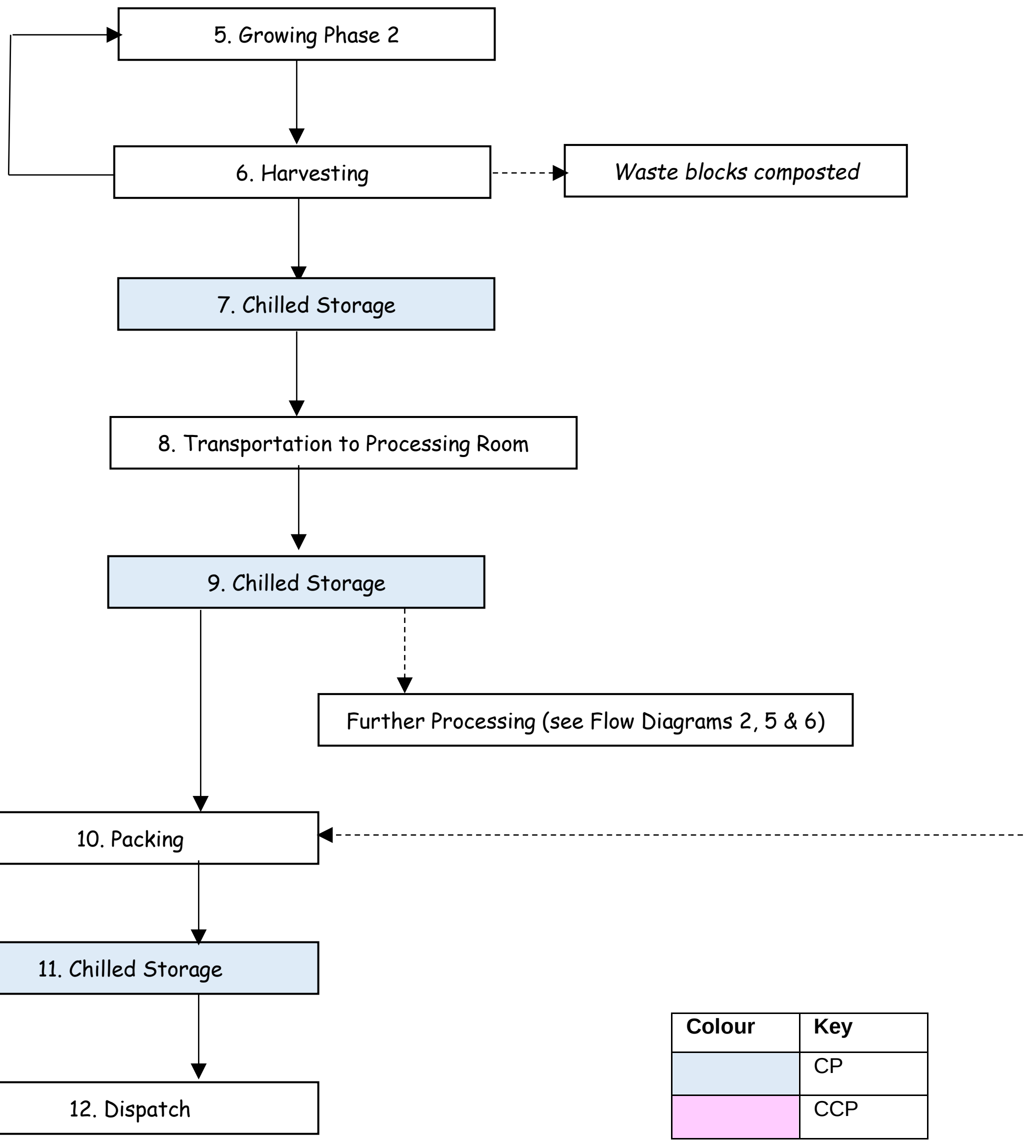
Control Point (CP) – The step is not necessarily identified as a critical process step, however, it is considered that specific controls and critical limits must be applied and that the step requires specific monitoring in order to demonstrate process control.

Critical Control Point (CCP) – A step in the process at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to a safe level. Critical limits are specified and monitoring to determine compliance is required.

Table 3: Process Flow Diagram for Fresh Mushrooms: Shitake & Oyster







Colour	Key
	CP
	CCP

5.5.5 Hazard Analysis Plan - Risk Assessments

Product: 1. Fresh Mushrooms – Shiitake & Oyster

Date: June 2016 Prepared by: Cynan Jones

Process Step	Hazards & Causes	Risk Assessment of Hazards			Control Measures	Answers to Questions on the Hazard Analysis Decision Tree					GMP / CP / CCP		
		Likeli-hood or Risk	Severity or Impact on Health	Sign-ific-ance		1	1 a	2	3	4	GMP	CP	CCP
1a. Collection and Intake of Shitake Blocks in sealed bags	Presence of infections such as Trichoderma (toxin-producing) and Penicillium moulds on growing substrate	1	2	2	Purchase from the approved supplier register (YAF-xxx); blocks are pre-sterilised by the manufacturer	Y		N	N			✓ CP1	
					Visual checks of blocks for presence of Trichoderma and Penicillium moulds	Y		N	N			✓ CP2	
	Contamination with infections such as Trichoderma (toxin-producing) and Penicillium moulds on growing substrate due to damaged bags	1	2	2	Visual checks of bags for damage	Y		N	N			✓ CP3	
1b. Intake of Oyster Blocks in sealed bags	Presence of infections such as Trichoderma (toxin-producing) and Penicillium moulds on growing substrate	1	2	2	Purchase from the approved supplier register (YAF-xxx); blocks are pre-sterilised by the manufacturer	Y		N	N			✓ CP1	
					Visual checks of blocks for presence of Trichoderma and Penicillium moulds	Y		N	N			✓ CP1	

	Contamination with infections such as Trichoderma (toxin-producing) and Penicillium moulds on growing substrate due to damaged bags	1	2	2	Visual checks of bags for damage	Y		N	N			✓ **CP3**	
1c. Intake of packaging materials	Presence of foreign bodies, pathogens or chemicals due to contamination during manufacturing	1	1	1	Purchase of food grade packaging materials from the approved supplier register (YAF-xxx)	Y		N	N		✓		
	Cross contamination with foreign bodies and pathogens due to damaged or soiled packaging	1	1	1	Visual checks of packaging and delivery vehicle. Incoming delivery form (YAF-xxx)	Y		N	N		✓		
2a. Unloading Shitake blocks and placing in Incubating Room 1 (still sealed in bags)	Cross contamination with moulds or foreign bodies due to damage to bags during unloading	1	1	1	Trained operator	Y		N	N		✓		
2b. Chilled on-site storage of Oyster blocks (still sealed in bags)	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from the environment	1	1	1	Adherence to pest control policy	Y		N	N		✓		

3. Growing phase 1 (still sealed in bags)	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from the environment	1	1	1	Adherence to pest control policy	Y		N	N		✓		
4. Transfer to Growing Room 2 or 3 (bags opened and blocks placed on shelving)	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from operator	1	1	1	Adherence to operator hygiene policy; wearing of blue disposable gloves	Y		N	N		✓		
	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms or cleaning chemicals from scissors	1	1	1	Adherence to cleaning schedule for utensils	Y		N	N		✓		
	Chemical cross contamination from cleaning chemicals	1	1	1	Adherence to cleaning schedules for shelves and growing unit. Allow shelves 1 hour to dry following cleaning before placing blocks on them.	Y		N	N		✓		
5. Growing Phase 2	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from the environment	1	1	1	Adherence to pest control policy; routine maintenance of container	Y		N	N		✓		
6. Harvesting (NB. blocks can be re-used around 3 times,	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from operator	1	1	1	Adherence to operator hygiene policy; wearing of blue disposable gloves	Y		N	N		✓		
	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms or chemicals from utensils	1	1	1	Adherence to cleaning schedules for utensils	Y		N	N		✓		

repeating steps 5 and 6)	Presence of spoilage microorganisms causing rotting of mushroom	1	1	1	Visual inspection; disposal of rotten mushrooms (NB. Natural colour blemishes are acceptable, these would be processed into dried product rather than sold fresh)	Y		N	N		✓		
7. Chilled storage (on-site)	Growth of spoilage microorganisms due to high temperature	1	1	1	Chilled temperature 3 – 5°C, only temporary storage until all mushrooms harvested	Y		N	N			✓ **CP4**	
	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from the environment	1	1	1	Mushrooms stored in lidded plastic containers	Y		N	N		✓		
8. Transportation to Processing Room	Growth of spoilage microorganisms due to high temperature	1	1	1	Mushrooms pre-chilled; 5 mins journey	Y		N	N		✓		
	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from the environment	1	1	1	Mushrooms stored in lidded plastic containers	Y		N	N		✓		
9. Chilled storage (Processing Room)	Growth of spoilage microorganisms due to high temperature	1	1	1	Chilled temperature 3 – 5°C	Y		N	N			✓ **CP4**	
	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from the environment	1	1	1	Mushrooms stored in lidded plastic containers	Y		N	N		✓		
10. Packing into boxes	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from operator	1	1	1	Adherence to operator hygiene policy; wearing of blue disposable gloves	Y		N	N		✓		

11. Chilled storage	Growth of spoilage microorganisms due to high temperature	1	1	1	Chilled temperature 3 – 5°C	Y		N	N			✓ **CP4**	
	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from the environment	1	1	1	Mushrooms stored in lidded cardboard boxes	Y		N	N		✓		
12. Dispatch (ambient) – typically same day as harvesting	Cross contamination with foreign bodies, spoilage and pathogenic microorganisms from the environment	1	1	1	Mushrooms stored in lidded cardboard boxes within plastic containers	Y		N	N		✓		

SUMMARY of CP/CCPs: Product 1. Fresh Mushrooms – Shiitake & Oyster

Process Step	CP/CCP	Critical Limits	Monitoring				Corrective Actions		
			Procedure	Frequency	Responsibility	Records	Procedure	Responsibility	Records
1a & 1b. Intake of Shitake and Oyster blocks in sealed bags	CP1	Every block has been sterilised	Recording of batch number and sterilising pot number	Each block	Cynan Jones	Batch and Sterilising Pot Record	Block removed and destroyed	Cynan Jones	Batch and Sterilising Pot Record
	CP2	Absence of green mould spots	Visual inspection	Each block	Cynan Jones	Intake Record	Block removed and destroyed	Cynan Jones	Intake Record
	CP3	No split or damaged bags	Visual inspection	Each block	Cynan Jones	Intake Record	Blocks re-sealed	Cynan Jones	Intake Record
7, 9, 11. Chilled Storage	CP4	Chiller temperature 4± 3°C [target 3 – 5°C]	Visual checks of display/internal thermometers twice daily; weekly check with calibrated probe	Twice daily checks / weekly check	Cynan Jones/ June Jones	Fridge temperature checks record	Products moved to an alternative chiller or disposed if > 8°C for > 4 hours?	Cynan Jones/ June Jones	Fridge temperature checks record

The Mushroom Garden system HACCP has been approved by both the UK Soil Association (UK based Organic certification)and SALSA (Safe and Locally Sourced Accreditation).((SALSA, 2020))and the Gwynedd Local Authority Environmental Health Department. It is thereby fully compliant with health and safety legislation. This is very important when establishing the system in other locations as it not only provides a template for the food regulatory systems in their locations but also instils a large degree of confidence in the system by the operators and regulators.

6 Analysis of measurements - energy input, yields of mushrooms, Nutritional values

The diagram below shows the data collected during the project (see Figure 27). Over a 12-month period, using the Mushroom Garden Snowdonia's growing rooms as a functional laboratory, several measurements were taken and recorded (see below). The after 6 months the lighting was changed from fluorescent light to LED of the same light intensity and measurements repeated. Calculations were made on the energy consumption of the growing rooms at various times during the year based on the power consumption of the internal fixtures and fittings, namely the lights, the centrifugal pump that draws air into the container and when required the heater.

There is a fixed regime for the container as follows:

Lights on for 12 hrs per day.

Pump on for 15 minutes every hour.

Heater on when required to maintain a temperature of 15degrees Celsius- in reality only about 5 days per annum.

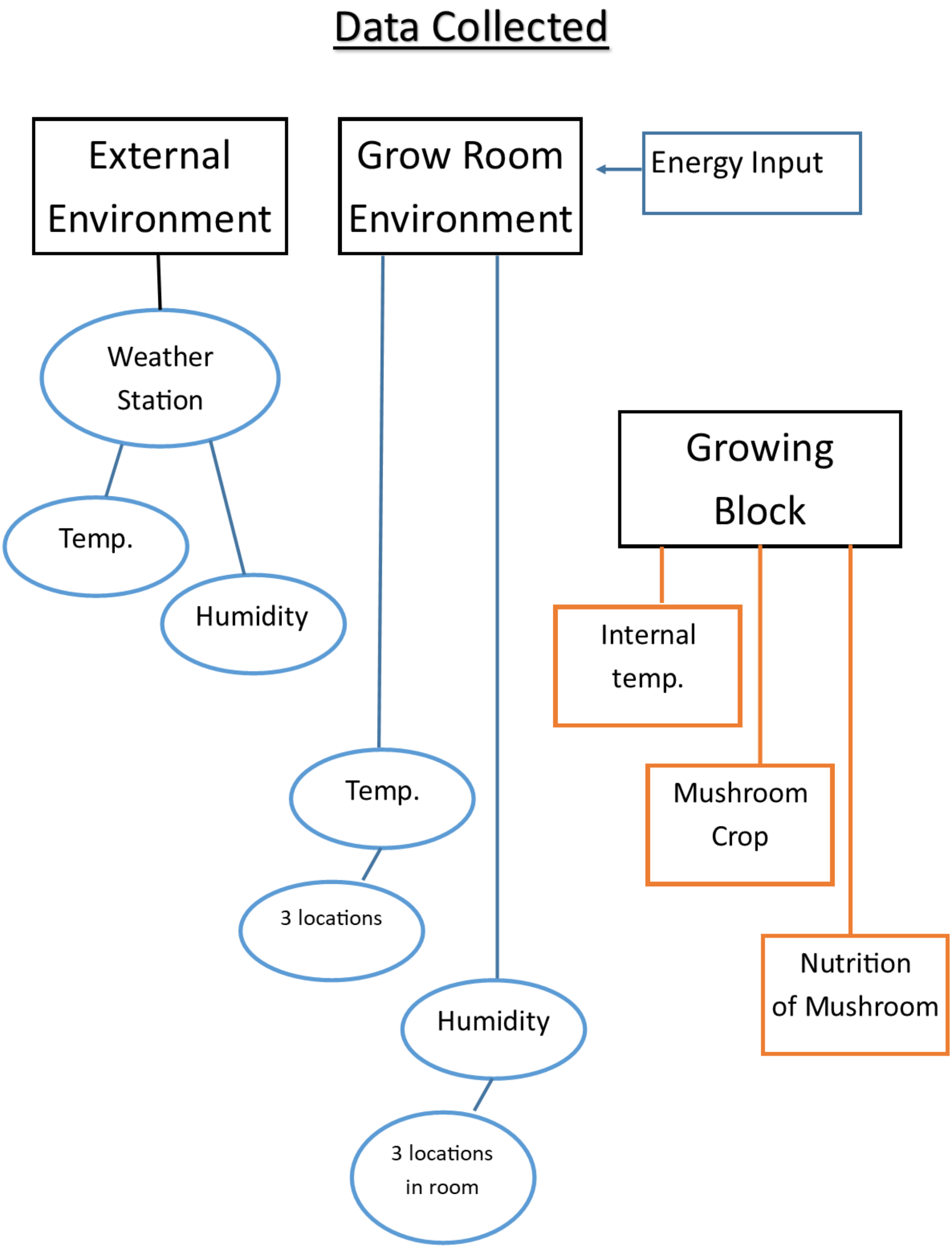


Figure 27: Diagram of data collected (Jones, 2020)

6.1 MEASUREMENT OF INTERNAL TEMPERATURE OF THE GROWING ROOM AT THREE LOCATIONS

Tiny Tag monitors were used to make the measurements placed on a low shelf at the front of the growing room, middle shelf centre of the growing room and top shelf at rear of the growing room.

6.2 MEASUREMENT OF INTERNAL HUMIDITY OF THE GROWING ROOM AT THREE LOCATIONS

Tiny Tag monitors were used to make the measurements placed on a low shelf at the front of the growing room, middle shelf centre of the growing room and top shelf at rear of the growing room.

6.3 MEASUREMENT OF INTERNAL BLOCK TEMPERATURE

Tiny Tag Probe monitors were used to make the measurements placed on a low shelf at the front of the growing room, middle shelf centre of the growing room and top shelf at rear of the growing room.

6.4 MEASUREMENT OF INTERNAL LIGHT OF THE GROWING ROOM

A testo 540 light monitor was used to make the measurements placed on a low shelf at the front of the growing room, middle shelf centre of the growing room and top shelf at rear of the growing room.

The monitor provided readings of the lux at the three locations.

The **lux** (symbol: lx) is the SI derived **unit** of illuminance and luminous emittance, **measuring** luminous flux per **unit** area. It is equal to one lumen per square metre.

Measurement of External Temperature and humidity

The measurements were made by a weather station in the vicinity of the growing rooms.

In addition to the monitoring information on the growing environment, measurements were also taken of the yield and nutritional values of the cultivated mushrooms which will be discussed below.

Yield of mushrooms from the blocks.

Nutritional values of the Shiitake and Wood Oyster mushrooms

Vitamin D values of Shiitake and Wood Oyster mushrooms

Conclusions

The results have allowed the system to be analysed for the first time and provide invaluable data for the future design and operation of the Mushroom Garden System. There follows a discussion on the results:

6.5 PRELIMINARY OBSERVATIONS

Without detailed analysis of the data captured to date the following can be confidently reported:

Temperature and humidity within the growing room is consistent throughout, therefore the current air circulating regime seems to be effective.

The Mushroom Garden system will therefore continue to use the ventilation regime of changing the air in the growing room every hour by having the air input pump on for 15 minutes every hour.

The growing blocks are generating heat while growing, the temperature within the blocks being on average 1.5° C higher than the growing room temperature for both Shiitake and Oyster blocks.

This is to be expected as the mycelium growing process generates heat as nutrients in the substrate are broken down by enzymes.

The external temperature has a profound effect on the internal temperature of the growing room. This leads to two questions:

Should the insulation of the growing rooms be improved?

Should the air intake system be changed so that external air is cooled or warmed before entering the growing room?

This is something that needs to be addressed and can be rectified by installing a heat exchange interphase on the air intake port in the growing room. Further research as to the cost and energy efficiency of such installations needs to be carried out as part of a thermodynamic profile of the system.

Yield and nutritional value are very similar under fluorescent light and LED.

This is of great importance as it shows that the system generates similar results in terms of the produce at a very greatly reduced cost.

Vitamin D content under LED x3 the content under fluorescent light.

There follows a detailed analysis of the nutritional value of the mushrooms. A crucial finding of the experiment was that LED light produces x3 the value of vitamin D in Shiitake.

This is a ground-breaking discovery that has never been demonstrated. The practical and commercial impact of this finding, although it needs, of course, to be replicated, is that higher value mushrooms can be produced at a lower cost. This information has been shared with a major mushroom grower in the UK (weekly yield 15tonnes Shiitake and Wood Oyster mushrooms) who is currently looking at the economics of converting their growing rooms to LED. Commercial sensitivity dictates that this producer cannot be named.

6.6 Nutrition

The analysis below shows how both Shiitake and Wood Oyster mushrooms are rich in essential nutrients, which are enhanced and concentrated when the mushrooms are dried. The analysis of the Vitamin D content is of particular significance as it as the Mushroom Garden System generates three times more of the vitamin in Shiitake mushrooms than current commercial growers, as demonstrated by the data by USDA National Nutrient Data base.(US Department of Agriculture, 2019) below (see Tables 2-5)The nutritional values, as a percentage of the weight, increases dramatically when the mushrooms are dried (weight loss 90% when dried so concentration increases). Particular attention should also be placed on the protein values of the dried mushrooms which are higher than some processed meats such as bacon.

Table 2: Fresh Shiitake Mushrooms source USDA National Nutrient Data base (US Department of Agriculture, 2019).

Table 4: Dried Shiitake Mushrooms source (Coleg Menai Food Technology Centre, 2020)

Nutrients	Amount
Basic Components	100g Contains
Protein	2.10g
Carbohydrates	5.20g
Water	86.69g
Ash	0.81g
Calories	
Total Calories	36.46Kj
Carbohydrates	
Dietary Fibre	1.00g
Sugar	1.00g
Other Carbs	3.10g
Vitamins	
Vitamin C	2.50mg
Minerals	
Iron	2.60mg
Sodium	21.98mg

Table 5: Fresh Oyster Mushroom source USDA National Nutrient Data base (US Department of Agriculture, 2019).

Typical Values	100g Contains
Energy	1492kJ/ 353kcal
Fat	1.0g
of which Saturates	0.2g

Carbohydrate of which Sugars	63.9g
	0.g
Fibre	11.5g
Protein	16.3g
Salt	0.03g

Table 6: Dried Oyster Mushrooms source (Coleg Menai Food Technology Centre, 2020)

Basic Components	100g Contains
Protein	3.31 g
Carbohydrates	6.09g
Water	82.0 g
Calories	
Total Calories	217 KJ
Carbohydrates	
Dietary Fibre	2.30 g
Sugar	1.08 g
Other Carbs	2.71 g
Vitamins	
Vitamin A	30.00 mg
Minerals	
Iron	1.33 mg
Sodium	18.00 mg

Table 7: : Fresh Shiitake Mushroom source USDA National Nutrient Data base (US Department of Agriculture, 2019)

Typical Values	100g Contains
Energy	660kJ/ 160kcal

Fat	2.0g
of which Saturates	0.2g
Carbohydrate	0g
of which Sugars	0.g
Fibre	24g
Protein	23g
Salt	0.03g

Most cultures would dry mushrooms before use not only to concentrate the nutrients but also to increase shelf life from 7 days to 12 months.

The Mushroom Garden has had a confidential report commissioned through Coleg Menai Food Technology Centre with an UKAS certified laboratory in 2018 that shows the Vitamin D content of Fresh Shiitake mushrooms grown in our system increases x3 under LED compared to fluorescent light of the same intensity and quality in the same environment. Vitamin D has several important functions. Perhaps the most vital are regulating the absorption of calcium and phosphorus, and facilitating normal immune system function. Getting a sufficient amount of vitamin D is important for normal growth and development of bones and teeth, as well as improved resistance against certain diseases. Mushrooms have long been known as a good source of vitamin D, however our work has shown how the vitamin content can be greatly increased with LED light at lower cost. The system yields approximately 200kg /week of mushrooms when in full production.

6.7 System mapping the growing and processing of mushrooms in the Mushroom Garden System

Below is illustrated a diagram of mushroom production (see Figure 28). The diagram illustrates the inputs and outputs that make the process work within the wider context of the economy and political and regulatory systems. Illustrating the mushroom growing process in this way also clarifies how the various processes are interconnected and are the basis of the new economic models of the circular and foundational economies which are developed in this dissertation. Whereas many of the individual illustrations and figures in this chapter have a linear and sequential format the diagram below brings the whole field of the experiment together as a systems mapping exercise.

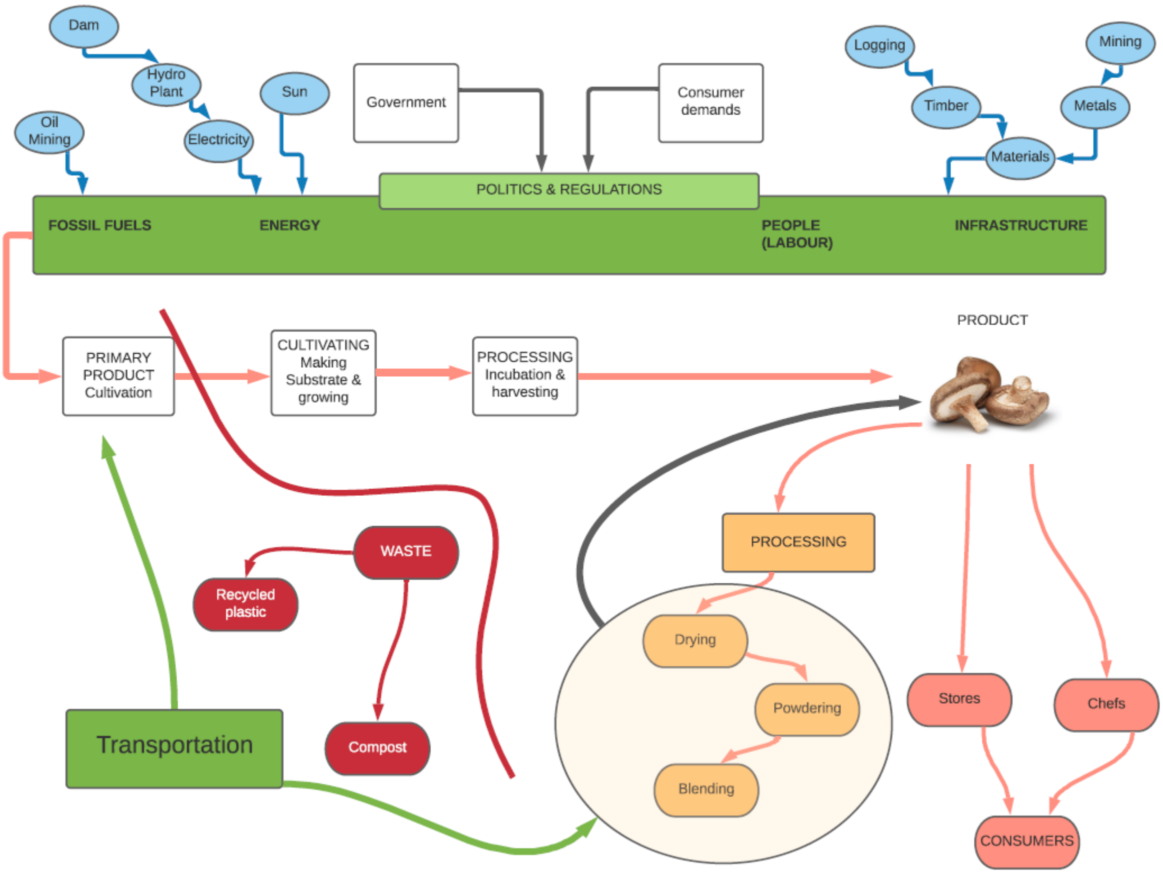


Figure 28: Diagram of The Mushroom Garden Processes (Jones, 2021)

7 APPLICATION OF SYSTEM

In order that the flexibility of application of the system can be demonstrated, three case studies are discussed. Each case study is introduced in sections 8.1-8.3. The case studies are real enterprises that have seen the potential that the Mushroom Garden system has to add value to their businesses in a way that fits with their business ethos and principles.

7.1 THE MUSHROOM GARDEN SNOWDONIA (CASE STUDY 1)

7.1.1 Background

This case study is the original full scale prototype for cultivating Shiitake and Oyster mushrooms. The growing units are converted shipping containers (see Figure 29) sited at Nantmor, Beddgelert Gwynedd, Wales. Just a few miles from the foot of Yr Wyddfa, (Mount Snowdon). The author farms 50 acres of land with his wife rearing Welsh mountain sheep. The growing units are sited on land rented from the National Trust near to the farm. The site was chosen as it had mains electricity and water plus excellent access none of which were available in the main farm buildings. The mushroom growing enterprise was originally established as a farm diversification project to provide a second income supported by the EU Regional Development Fund, Gwynedd County Council and Bangor University.

Figure 29: The Mushroom garden's Growing Units (Photo: Jones, 2021)

Figure 30: The Author harvesting Shiitake Mushrooms (Photo: Jones, 2021)

The original growing system concept was developed by another Welsh company (Humungous Fungus) that worked with the author to establish the Units at Nantmor (see Figure 30) and the farm diversification project supported the author to develop a consistent growing system and to undertake market research on the embryo business. There followed a 18 month period of business development creating a viable and profitable Shiitake production unit. There then was a period of maximising the production of Shiitake mushrooms initially and then Wood Oyster and at the same time building a customer base within the local community, and The Mushroom Garden as a business was born! It was during the next phase of development that the author realised the potential of the growing system by exploring the possibilities of establishing units for local production of quality, nutritional food in a range of different communities. Having worked with Humungous Fungus to establish the growing units at The Mushroom Garden, Humungous Fungus wanted to move on to other environmental projects in West Wales and agreed that The Mushroom Garden could claim the intellectual property relating to the system, thereby opening the door to explore the application of the system inn other settings. However, before that could happen the growing process had to be clearly described and as was the risk assessments and food safety certification awarded. A diagram of Case study 1 is shown below (see Figure 31).

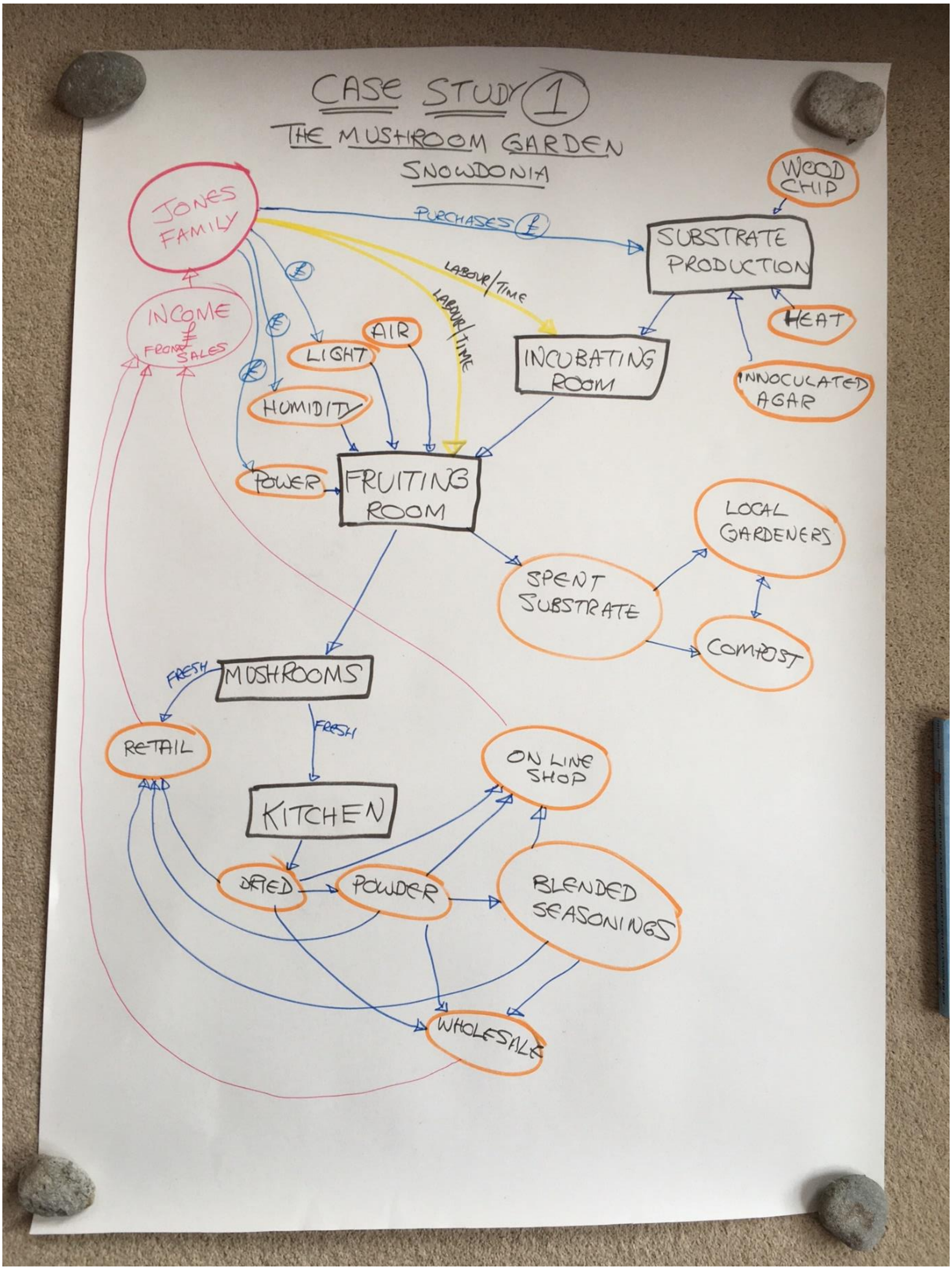


Figure 31: Diagram of The Mushroom Garden (Jones, 2021)

The unit has been operational since 2006.The unit can hold 300 growing blocks and produce yields of 150kg/week of Shiitake or Wood Oyster mushrooms. For the first few years the unit grew only Shiitake mushrooms but then moved on to Wood Oyster mushrooms also - both species are grown in the same environment and experience has shown that there are no negative effects from growing both in the same environment in terms of mushroom yields per block. There has never been an incident of cross infection in terms of Oyster mushrooms growing on the Shiitake blocks. Therefore, with careful harvesting, there is no mixing of harvested mushrooms. The business soon developed products based on the mushrooms, for example Dried Shiitake mushrooms and dried Oyster mushrooms - this means that there is very little waste, and the shelf life and storage time of the mushrooms is greatly increased from 7 days in a chiller for fresh to 12 months ambient for dried. Recent developments have seen the production of blended seasonings based on the mushroom powders made from the dried mushrooms. The fresh mushrooms are sold to local restaurants, delis, and farm shops whereas the dried products and seasonings are sold further afield all over the UK as they travel well and have a long shelf life. The used mushroom blocks are composted and offered to local gardeners as a mulch.

7.1.2 Sustainable food production

The main ingredient for making the growing substrate is oak wood chip and sawdust sourced from sustainable sources and is mostly produced by oak forest and coppice management and removal of windfall trees and branches. The suppliers of the chipped wood are private tree surgeons in Wales or the Welsh National Parks and the National Trust. These organisations are extremely environmentally aware with sustainability of the grown environments under their control and management is of prime importance to them. This means that The Mushroom Garden can be confident that the base material for the substrate is sustainable. Sawdust is sourced from oak furniture makers, and builders in Wales, or other craftspeople working with oak, such as timber framed house builders and environmental artists using oak. Energy input is low, so costs are sustainable for the business, and the fixtures and fittings of the growing rooms are all standard greenhouse kit with very low maintenance. There is need for labour input in terms of moving blocks and harvesting, however it is not heavy work, and all members of the family are involved and understand all aspects of the growing process, therefore making the family business sustainable should any individual be unable to perform his or her primary duties due to other commitments, holiday or illness.

7.1.3 Circular economy food growing

The growing substrate is basically a waste product from tree management, that is wood chip and sawdust which is sterilized and inoculated. Therefore, the growing process starts with a recyclable commodity. The wood is sourced locally if possible and Wales in general. The spent (used) substrate is returned to the land as mulch or compost for further vegetable growing and soil build up. Rod Gritten, an ecologist and gardener from Croesor, 3 miles from The Mushroom Garden, has been using the spent substrate for five years and has now a “no dig” regime for his garden - an excellent example of a closed circle in food production. “No-dig “ gardening is a way of gardening which does not involve tilling or digging the soil. The argument for not digging is that the soil “looks after itself”, relying on bacteria, fungi, and insects to break down organic material to provide plant nutrients and it allows for natural aeration through minute tunnels dug by earthworms and insects. However, the soil does need new sources of organic material on a regular basis, and this is introduced by layering new soil, organic compost, and mulch on to the garden’s surface. This layering not only provides nutrition to the soil, but it also keeps moisture in and greatly reduces the development of weeds.

The Mushroom Garden’s spent compost, i.e., the old fruiting blocks which have self-decomposed, has been found by Rod Gritten to be ideal for nurturing and protecting the soil. It must also be remembered that the spent blocks are full of old mycelium containing polysaccharides and proteins which again break down naturally to further enrich the soil and its various bacteria and other fungi providing a bountiful supply of sugars and nitrogen (*The Urban Guide to being Selfsufficientish*, 2018) Economically the income generated is “recycled” in the local economy - studies in the US and UK are consistent in showing that for every £100 income generated in a local economy a further residual £45 is generated within that economy (Taylor, 2020).

7.1.4 Foundational Economy business

As described above, the basis of the Foundational Economy is to meet the primary needs of a community within that community. There can be no more important need than nutritional food of high quality. The Mushroom Garden Snowdonia is a business that supplies food that meets the above conditions to local businesses and people and provides an income for a family so that they are able to live within their community. Currently The Mushroom Garden supports two full time equivalent jobs. Additional sales of the mushroom and mushroom products produced by the Mushroom Garden in Snowdonia, to a wider market actively imports capital into the family business which helps them to meet their needs. The spent growing substrate is given away to gardeners to use as a compost/mulch to grow fruit and vegetables. As described previously the Foundational Economy starts by addressing the needs of the community and not what the multinational economy insists that people need. This is what The Mushroom Garden does.

7.1.5 Food security

The Mushroom Garden Snowdonia supplies fresh mushrooms to local and regional customers, mainly Chefs and delis, greatly reducing food miles as the alternative suppliers are based in England or imported from the Netherlands or even the Far East. The business has also established a commercial kitchen at the proprietors' home which processes the fresh mushrooms into dried and powdered products. This happens within half a mile of the growing rooms. These products are distributed locally by the proprietors and regionally by local and regional food distributors and couriers. Local production and processing of the mushrooms not only reduces food miles but also reduces the opportunity for cross infection of food and stock shrinkage in transportation (i.e. fresh food spoilage or pilfering). There is no dependence on imported material or ingredients to make the products. The growing substrate (wood chip and sawdust) are sourced locally or regionally thereby reducing the supply chain with a resulting reduction in supply interruptions.

7.2 BATTLESTEADS HOTEL (CASE STUDY 2)

7.2.1 Background

This case study is the carbon neutral Battlesteads Hotel in Northumberland, England (see Figure 32).

Figure 32: The Battlesteads Hotel and Restaurant (Photo: Battlesteads Hotel from www.battlesteads.com with owners' permission)

The Hotel is situated in the village of Wark in Northumberland. The establishment is more than a traditional Hotel comprising of a bar and Restaurant. The proprietors are passionate about their ales, beers and wines. The business prides itself on serving locally sourced produce, complimented by their own home-grown fruit and vegetables, prepared to an exceptional standard by their chefs and kitchen team (see Figure 33).

Figure 33: Battlesteads Hotel vegetable garden (Photo: Jones, 2021)

Below is a diagram of the Battlesteads Hotel's business and activities (see Figure 34).

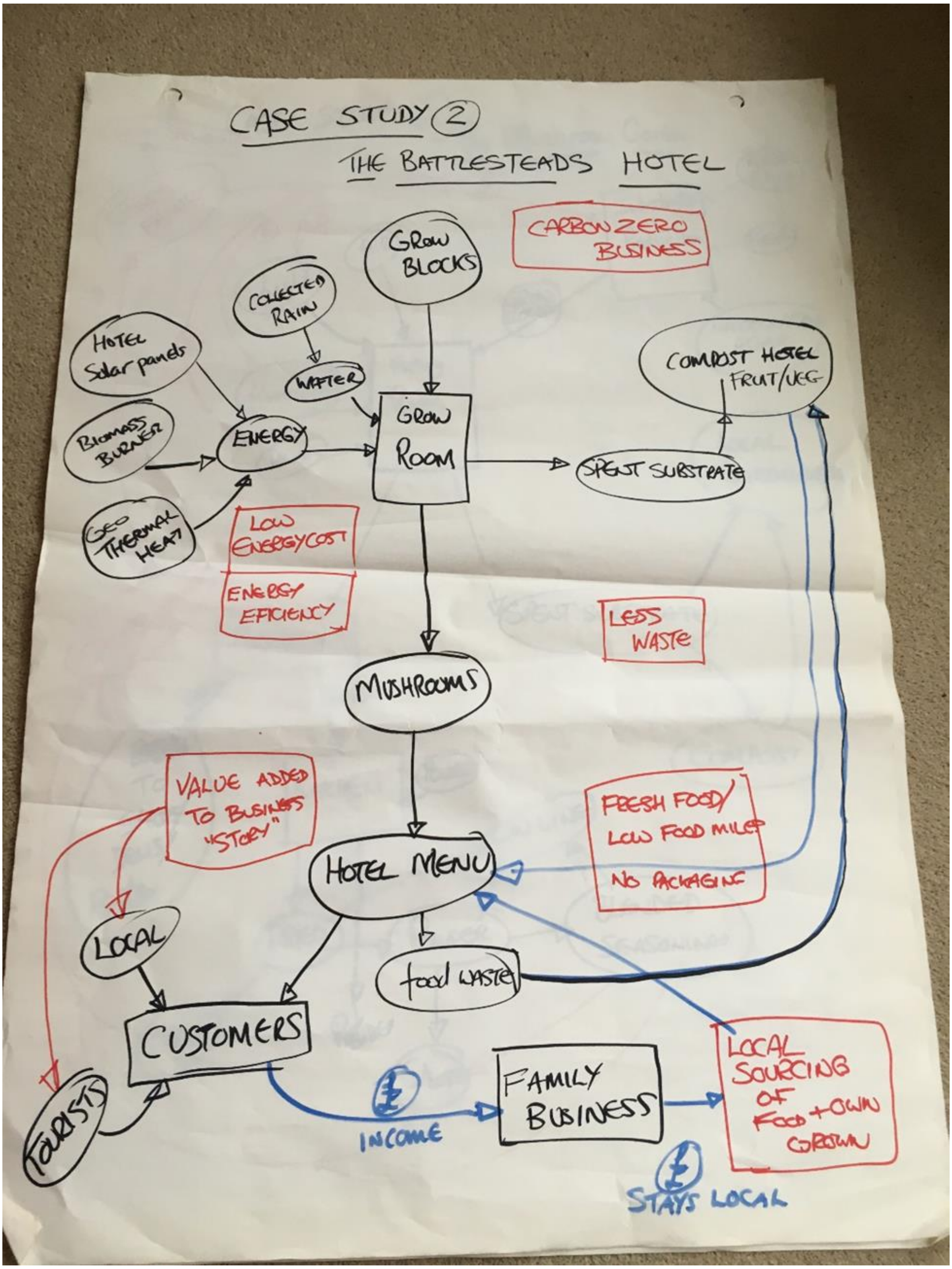


Figure 34: Diagram of The Battlesteads Hotel Northumberland (Jones, 2020)

The Mushroom Garden was approached by the Battlesteads Hotel to establish a Shiitake and Wood Oyster growing unit in their vegetable garden, having met the Author at a food event in London in 2016. The author was commissioned to work with the Battlesteads owner /proprietors to establish the unit. The hotel felt that the values ingrained in the Mushroom Garden System was a perfect fit for their business i.e. low carbon production of nutritious food in a sustainable manner and felt that it added value to their business and customer experience. Sustainability is intrinsically woven into every aspect of what they do. From features such as the carbon-neutral heating and hot water system, the extensive gardens with two polytunnels which provide fresh fruit and vegetables for the kitchen throughout the year, to undertakings such as their locally sourced organic toiletries, the use of empty toilet roll inners for potting seedlings and the wormeries munching through kilos of food waste turning it into compost. The Battlesteads is proud to be the greenest hotel in Northumberland. Of the 173 hotels across the county, they were the first to install a carbon-neutral heating system and one of only two to hold a Gold Award from the Green Tourism Business Scheme.

7.2.2 Sustainable food production

The main ingredient for making the growing substrate is oak wood chip and sawdust sourced from sustainable sources and is mostly produced by oak forest and coppice management and removal of windfall trees and branches. Some of the sawdust is sourced from oak furniture makers. Currently the Hotel is buying in growing blocks for both Shiitake and Oyster mushrooms, however the aim is to produce their own substrate. This is a medium term (5yr) aim as there needs to be research into the establishment of a block producing unit at the Hotel. This would involve significant investment and an assessment of financial viability. Energy input is low so costs are sustainable, especially as the Hotel generates its own low carbon energy from a combination of solar, geothermal and biomass electricity and heat production. The mushroom growing room and the fixtures and fittings of the growing rooms are all standard greenhouse kit with very low maintenance. There is need for labour input however it is not heavy work and all members of the family and staff can get involved and understand all aspects of the growing process therefore making the family business sustainable should any individual be unable to perform his or her primary duties.

7.2.3 Circular economy food growing

The growing substrate is basically a waste product from tree management, and the spent (used) substrate is returned to the hotel's fruit and vegetable garden as mulch or compost for further vegetable growing and soil build up. -This an excellent example of a closed circle in food production. Economically, the income generated is "recycled" in the local economy – as noted already, many studies in the US and UK are consistent in showing that approximately 52 % of income generated in a local economy stays in that economy (Barnhill, 2020).

7.2.4 Foundational Economy business

As described above, the basis of the Foundational Economy is to meet the primary needs of a community within that community. The Battlesteads Hotel is a business that supplies locally sourced and own-grown high-quality food to local customers and people and provides an income for a family and staff so that they can live within their community. Additional sales to a wider market actively import capital into the family business which helps them to meet their needs. The spent growing substrate is given away to gardeners to use as a compost/mulch to grow fruit and vegetables.

7.2.5 Food security

Local production and consumption mean less food miles which is important for security. The transportation of food over large distances not only creates food insecurity but also increases the carbon footprint of the food production and distribution network. Similarly, the growing substrate is locally available, again greatly increasing security and reducing the prospects of interruption of supply.

7.3 AWEN BRIDGEND (CASE STUDY 3)

Awen Cymru is a social enterprise in Bridgend Wales, providing training and work opportunities for local individuals who have learning difficulties or other life challenging conditions (see **Error! Reference source not found.**).

Figure 35: Awen Trust Staff and employees (Photo from Awen Website with permission off Awen Cultural Trust)

The Trust has recently taken over a number of the local authority's amenities including a theatre, libraries and sport centres and the Bryngarw country park. The Park has a restaurant /wedding venue and a large market garden with farm shop. As can be seen below (see Figure 36) the various elements of the enterprise are interlinked and provide a wide economic base for the Trust. The range of activities also create income for the Trust and a range of work and training opportunities for the workers and trainees.

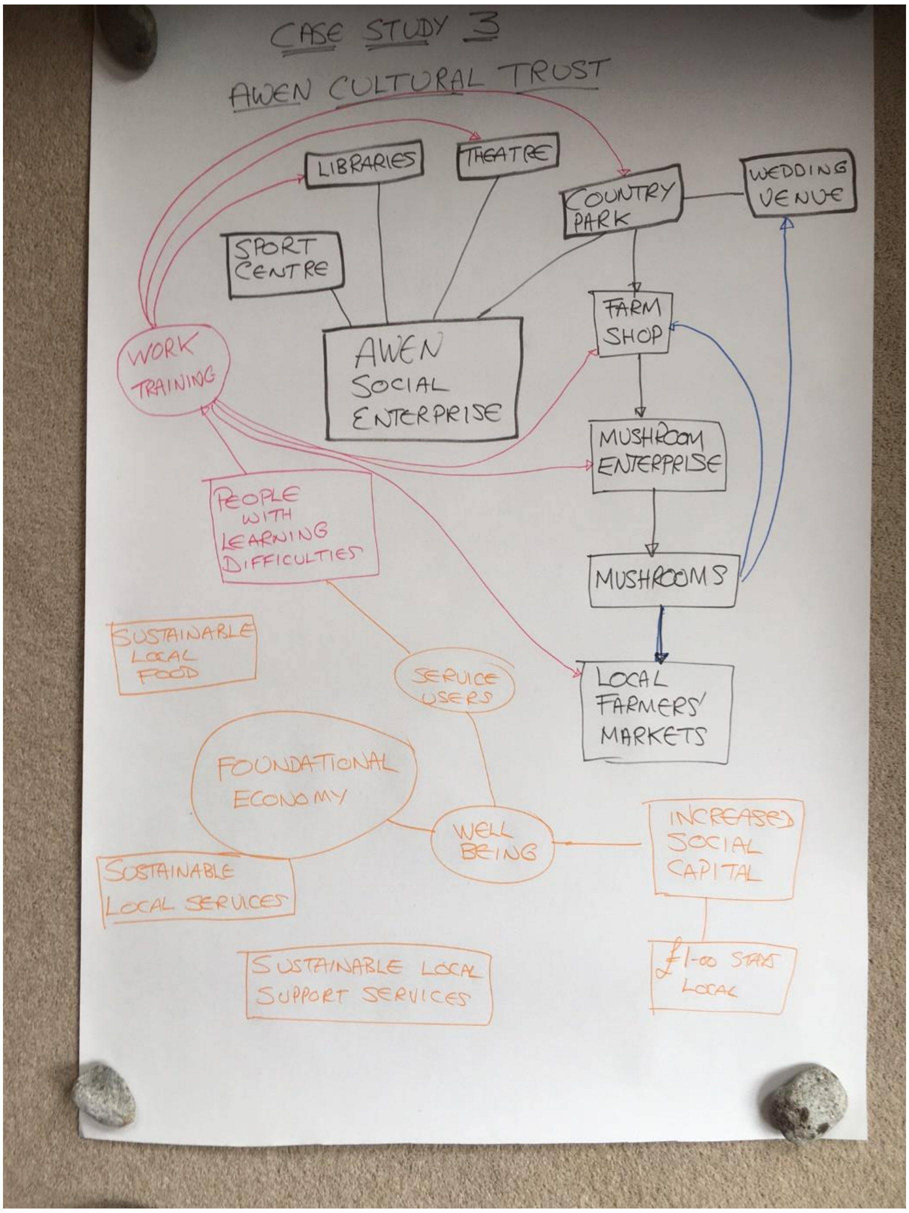


Figure 36: Diagram of Awen Cultural Trust Bridgend (Jones, 2020)

7.3.1 Background

Awen Cultural Trust was established in 2015 as a charitable organisation with objectives to enhance cultural opportunities in Bridgend and the wider region. Its purpose is to 'Make People's Lives Better' by providing space and opportunity for people to enjoy vibrant cultural experiences that inspire and enhance their sense of wellbeing. Their values are enshrined in everything they do, from how they interact with customers and partners to how they work internally with colleagues. The four core values are noted in Awen's web site (Awen-Wales.com) and can be summarized as follows. Awen Cymru looks at fresh, creative ways to improve continually what they do and how they do it, taking into consideration and responding to the changing world locally and globally. The organisation believes in collaboration both internally and externally with stakeholders and partners. Working with people who have challenges to overcome in their lives, Awen believes in empowering people to reach their full potential, and this involves fairness in all its dealings both with colleagues and one another and the communities they serve.

One element of what Awen Cymru does is the B-Leaf project, which is a work-based initiative for adults with disabilities based within the beautiful Bryngarw Country Park. It operates as nursery and garden centre and provides an extensive training programme in horticulture and grounds maintenance. Trainees are supported by a team of dedicated staff who help them progress in whatever way they can to develop new skills, make new friends and ultimately lead more independent and fulfilled lives. Customers can buy a range of plants and flowers all year round from B-Leaf as well as summer pots and hanging baskets filled to their own specification. As a way of increasing the training and business opportunities at B -Leaf the Mushroom Garden was approached with the aim of establishing a Shiitake and Oyster mushroom growing enterprise. This activity would provide new experiences for the service users, diversify the range of products cultivated and provide anew income stream to the project. This is an exciting development for the Mushroom Garden as the company believes the system is ideally suited to a social enterprise and specifically an enterprise working with people who have learning challenges.

7.3.2 Sustainable food production

In the initial period, growing substrate will be supplied by The Mushroom Garden. However, there is great potential for Awen to create their own substrate sourced from the woods of the country park and other sites that they have. The growing unit is a replica of the Mushroom Garden Unit so, as mentioned above, energy input is low so that costs are sustainable, and the fixtures and fittings of the growing rooms are all standard greenhouse kit with very low maintenance. The need for labour input, however, provides an opportunity to create employment and training for several the Trust's service users. A team will be trained so that enough can operate the system.

7.3.3 Circular economy food growing

As mentioned above the growing substrate is basically a waste product from tree management, which can be sourced from the Trust's country park and the spent (used) substrate is returned to the land as mulch or compost for the onsite market garden.

The mushrooms produced will be sold in the market garden and to nearby businesses and to the general population through farmers' markets and will feature on the menu in the wedding venue also situated in the country park. The local retention of income generated by the business will also be a feature of the project as many of the Trust staff and service users live locally.

7.3.4 Foundational Economy business

As described above the basis of the Foundational Economy is to meet the primary needs of a community within that community. The Awen Cultural Trust is primarily a business that provides a locally based service to service users with learning difficulties and other challenges. However, by taking over numerous assets from the Local Authority they also provide leisure facilities to the local community. As a not-for-profit trust their business model also provides opportunities for the training of service users and education of the wider community on matters such as food cultivation and environmental issues.

7.4 Summary of The Mushroom Garden's contribution to Case Studies

Each case study demonstrates how the mushroom growing experience provides added value to the three enterprises in a sustainable way and on a local level is addressing the global issues of food security and sustainability within the Circular and Foundational economies. Additionally, it is important to note that the added value manifests itself in different ways within the three case studies. In case study 1 the mushroom growing activities were originally a secondary income to a farm as a diversification project and has evolved into a separate standalone business. This means that the family business is more secure and sustainable.

The Battlesteads Hotel prides itself on its environmentally friendly and carbon zero record and saw the mushroom growing system as a complementary food production unit in the Hotel's fruit and vegetable garden. The system fits well with the Hotel's principle of local sourcing of ingredients for the restaurant and the cyclical nature of the process where the spent compost is returned to the garden as mulch and compost.

Awen Trust saw the mushroom unit not only as a source of produce for the restaurant and the farm shop but also as a new experience for the trainees and workers and therefore providing social value as well as economic value for the community.

8 DISCUSSION AND CONCLUSIONS

The dissertation has been framed by a Systemic Design approach based on a full-scale prototype of the mushroom growing system with the research carried out by the operator of the system. It is a real life codesign laboratory. The research followed two distinctive but parallel courses. Firstly, technical investigations into the growing conditions within the system to achieve optimum yields and quality of mushrooms. Secondly, investigating the application of the growing system as a contribution to the new emerging economic models and the global challenges that need to be addressed in the Post-Anthropocene. The Systemic Design approach has enabled a complex system with many variable components to be analysed by the collection of data from the growing system and technical details for the nutritional value of the mushrooms produced. In addition, the approach has enabled the researcher to understand and illustrate how the growing system interphases with many aspects of the communities it serves on a local basis and how such an approach highlights the exciting range of applications that the system has (in addition to the case studies) on a world-wide basis. This has also allowed the research to truly move from the local to the global and shows how a small-scale food producing unit can help to address some of the worldwide challenges facing the production, distribution and consumption of food.

8.1 THE MUSHROOM GARDEN SYSTEM'S CONTRIBUTION TO THE FIELD OF MUSHROOM CULTIVATION.

8.1.1 Technically

The Mushroom Garden System has some unique qualities which set it apart from other cultivation systems and this stems from its original purpose as a farm diversification project to provide a second income to farmers and growers. This meant that the system had to be small scale, compact and easily replicated, with simple construction and utility's needs. The Mushroom Garden Snowdonia has since taken the system on a journey which makes it flexible and applicable to many situations, both in urban and rural settings. All the component parts are readily available and can be sourced locally or regionally in many countries. The system is designed to be as automated as possible with light, temperature, humidity, and airflow programmed using simple greenhouse technology. Labour input in the basic system is not intensive, and the skill set required to operate and manage the system is minimal. Training of workers is simple and, as has been shown in one of the case studies people with learning difficulties can work the system effectively. The energy input is low and during the research for this dissertation the system has been made even more energy-efficient by replacing standard fluorescent lighting with LED lights. The system is also modular so increasing growing capacity involves the simple addition of more growing rooms (i.e., shipping containers). The whole process takes 12 weeks from spawn production to harvesting making it a very fast turnaround to produce nutritious food. The system can be established anywhere where there is a power supply of electricity, mains or locally generated and water.

8.1.2 In Application

From its original concept of being a system to provide a second income to farmers the system now can be a stand-alone business suitable for a range of applications as demonstrated by the case studies, from small family businesses to sustainable service businesses and social enterprises. My view is that it is ideally suited to fit in with other food growing enterprises both rural and urban and especially for community groups and social enterprises. It is also a perfect fit for the new economic models of the Circular and Foundational economies and can be a strong advocate for food security, as the food is produced as near as possible to where it is consumed. It is also founded on principles of sustainability as the growing substrate (i.e., wood chips and straw or other organic matter) is available in most communities. There follow examples of how The Mushroom Garden system complements the work of social enterprises in Wales that are developing food related projects. There are examples of community based approaches and methodologies and some underpinning "political" thinking.

Mhairi McVicar, Partneriaeth Ogwen and Sel Williams

In addition to changing economic models within our communities there has also been a recent change in approach to community development processes. We have seen the rise of community development as a demonstration of civic action. The food agenda has played an important part in these developments as described in the following examples. The author of a 2020 article published in *Architecture and Culture*, Mhairi McVicar reflects on a community project in Grangetown, a district of Cardiff (McVicar, 2020). The article follows the development of a community facility, café, meeting space and growing space, in an old bowling pavilion in the heart of the community. Driving the project was not only the feeling that a group of local residents wanted to "do something" with the asset but that the austerity imposed by central government had led to a reduction in community services and the maintenance of once proud community assets. The triple incentive of getting a place to meet, eat and grow was the cement that held the gathering of residents together. They did not describe themselves as a community group and certainly did not claim to represent anyone other than "Us".

The Cardiff University School of Architecture became involved through the University's Community Gateway Programme that arranged for undergraduate students to work with communities on projects, and this involvement proved invaluable to this project in many ways. For example, the student's input assisted the community to conduct surveys and consultations and to visualise the future for the building in question. The students benefited from getting actively involved with a community to work on a real project. It was a symbiotic process, excellently described by one of the gathering as "a relationship not an affair!!". The students were also able to assist in developing a brief for the building in order that architects could be commissioned. The Mushroom Garden system would be a perfect fit in terms of values and vision for the development of this inner-city project should it wish to develop their growing activities. This is because the system, both in terms of structures and operation, can be fully embedded within a community setting. The community group, or a smaller sub-group, would be trained in the operation of the system and the distribution of produce and market opportunities for income generating sales that can be reinvested in the community. The spent growing substrate can be reused in other community growing projects as mulch or compost. Every step in the process has to have community buy in to the concept and community ownership of the enterprise.

Cadwyn Ogwen

This Project was established in response to the Covid-19 pandemic in the Ogwen Valley, based at Bethesda, Gwynedd. Cadwyn Ogwen is a system for connecting local food producers with customers in the community and has and still is of great help to isolated and vulnerable individuals and families who have suffered economically and emotionally during the pandemic. Cadwyn Ogwen is operated by the local economic and community development social enterprise, Partneriaeth Ogwen, in partnership with another social enterprise, Fferm Moelyci, which operates a farm, fruit and vegetable growing enterprise, shop and a café. The system works by establishing an on-line platform for producers where customers can place orders. The orders are then made up, boxed and delivered to the customers with Partneriaeth Ogwen's electric vehicle charged from Ynni Ogwen, the local community owned Hydro Scheme. The Mushroom Garden Snowdonia is a supplier to Cadwyn Ogwen. The next stage could be the establishment of a growing unit at Fferm Moelyci to supply Cadwyn, the shop and café, again a perfect fit to the existing project and enterprise. Building onto Cadwyn Ogwen's success, the mushroom growing enterprise can provide the community with nutritious food grown and consumed locally. Any excess produce, not needed for Cadwyn Ogwen, could supply the Moelyci shop and help to create income for the social enterprise. The spent substrate will be composted for use in the growing units and plots of the farm.

Communitisation

Sel Williams, community activist and retired lecturer at the Department of Lifelong Learning at Bangor University, has coined a phrase to describe the increasing role of community and social enterprises providing products, services and managing assets in the community. This leads on from the principles of the Foundational and Circular economies – '*Cymunedoli*' in Welsh, which this author has translated as 'Communitisation'. This is a very important and innovative word, politically describing the transfer of economic power to communities rather than either the private sector or the various levels of the public sector, including Central Government (nationalisation). The food economy will need to adopt this model in order that the food supply chain is reduced, and nutritional food can be produced and consumed within communities. The Mushroom Garden system is a perfect fit for this approach in that communities can control the means of production and distribution of nutritious food.

8.2 RELEVANCE OF THE SYSTEM TO THE MAIN THEMES

8.2.1 Critical concepts for the future of cities and regions as demonstrated by the case studies.

The mushroom growing system is robust and flexible to meet the needs of a range of communities. Individuals can be trained to use the system in a few days and the skill level required is low. As the system is modular (i.e., based on converted shipping containers) upscaling is achieved by commissioning more containers. In an urban area, public services can be very useful in upscaling, for instance by organising supplies of wood chip from municipal parks and roadside tree-surgery. The system fits perfectly with community food growing projects, city gardens and farms.

8.2.2 Sustainable production of food

The substrate to grow the mushrooms is wood oak chip and sawdust. It is sourced from local sustainably managed woodlands and traditional furniture makers. Energy input is low, at a daily cost of approximately £6.00 and there is continuing development on increasing the energy efficiency of the process. In addition to this, the Battlesteads Hotel generates its own electricity by solar panels. The growing rooms are of low maintenance with respect to the equipment and fittings so that it keeps costs to a minimum. Labour input is low grade in terms of skills and the work is not heavy. Therefore, it is ideal for part-time workers and/or family members on shared households to undertake.

8.2.3 The Circular Economy

The growing substrate is waste product from wood production. The used substrate, i.e. material left after the mushrooms have been cultivated and harvested, is returned to the land through gardeners and farmers as mulch/compost/soil build-up material and water retention material. *The Handbook of Waste Management* from 2009 discusses the importance of reducing and reusing waste in the food industry (Osterrgren, 2009). The book demonstrates that there are clear economic benefits to the industry if a circular economy approach is taken in food production in general. It secures clear environmental benefits to the planet by efficient use of ingredients and raw materials and reducing waste. The book discusses strategies to address the issues of waste production and various re-usage strategies are discussed such as tight supply chain management, capture and re-use of water and the re-usage of organic waste from production to cultivate other foods. These approaches have been developed by mushroom growers in recent years, such as growing Oyster mushrooms on used coffee grains and also spent hops from breweries. Both these substrates have been trialled successfully by The Mushroom Garden.

The Mushroom Garden system mirrors such strategies. Closed circle food production is critical to future development as it keeps production locally and thereby reduces the carbon footprint of the enterprise as well as waste and pollution. Another Circular aspect of the system is that income generated from the sale of mushrooms is spent locally by the business. The economic impact of keeping spending locally is demonstrated in a report by the New Economic Foundation (New Economic Foundation (Consulting), 2014) The findings were that for every £1.00 invested or generated in a community 52p is retained in the local economy, furthermore every £1.00 spent generates a further 71p in the local economy.

8.2.4 The Foundational Economy

A basic principle of the Foundational Economy is to supply a community's needs as the basis of a local economy. Those needs may be physical, such as basic services, utilities, and food, but also social, such as health, education, and security. All three case studies demonstrate the process of local production, distribution and purchasing of food within their communities and as such demonstrate a perfect fit for the Foundational Economy principle. The units are very robust and can be sited within most communities, urban or rural such as city courtyards, urban farms, traditional or vertical, or gardens. In fact, any communal space with access to clean water and single-phase electricity is suitable as a site. The main advantage is that the produce can be grown all year round as the cultivation conditions are carefully controlled. It therefore makes it possible to provide a consistent supply of nutritious food to a community from within that community.

8.2.5 Food Security

In all cases studied the fresh products travel very little food miles - no more than 20 miles and, in the case of the Battlesteads Hotel, about 20 meters! Therefore, the food is produced and purchased in the same vicinity. The raw material used to make the substrate can be sourced locally, such as wood chip and sawdust for Shiitake, straw for Oyster mushrooms or, in fact, any organic material including processed organic material such as paper. Reducing food miles is crucial to reduce food insecurity and carbon footprints, and to shorten the food chains. Such measures have been brought into close focus recently with the Covid -19 crisis and on-going uncertainties with supply chains from the EU following Brexit. The model studied in this dissertation is looking to the future of Agro-architectural application for transition to the Post-Anthropocene era in cities and regions where people, other species and technology benefit from each other and flourish by way of symbiosis. These growing units are situated within the communities they serve, reducing food-miles and dramatically reducing supply chains.

8.2.6 Post Anthropocene

A fundamental concern of the Post-Anthropocene epoch will be feeding the world. On a global scale geo-political co-operation will be essential as will environmental controls and soil and habitat regeneration. Having said this, localizing the production and consumption of food, shortening the food web and communitisation of production and distribution can play a major part in reducing carbon footprints. Cumulatively, this can have a major effect on slowing down and reversing planetary ecological and environmental challenges. The principles underpinning the Mushroom Garden system - communitisation, sustainability, food security leading into both the Circular and Foundational economies - and their practical implementation described in the case studies, demonstrate the flexibility and efficiency of localised food production. In the current environment of drives towards energy efficiency the recent developments within the Mushroom Garden system have greatly decreased the energy consumption and therefore reduced the carbon footprint.

8.3 FUTURE VISIONS

Recent economic models, political instability, environmental catastrophes, and pandemics beyond individual control do not respect traditional physical or ethical boundaries, nor the boundaries identified for global sustainability. Therefore, new approaches and processes need to be developed to ensure food sustainability and security. Communitisation provides one clear answer, and The Mushroom Garden System can be a major contributor in terms of food production in the Post Anthropocene epoch. This is, primarily due to its production of nutritious food from easily accessible organic waste, and the requirement for a relatively small area of production and energy efficiency.

This dissertation is preparing the way for the next part of the Mushroom Garden System's journey. The future follows two paths which can be stand-alone routes to the development of the system but can be integrated to produce a result that is of greater value.

8.3.1 Technological Advances

Power

Some developments have already been introduced into the system during this present research, mainly changing the lighting system to LED from traditional fluorescent lights. This has greatly reduced the cost of lighting and, as a major plus, has not reduced the yield or quality of mushrooms. Moreover it has resulted in a threefold increase in vitamin D content (see appendix 2). However, there remain energy challenges. For example, air is drawn into the growing unit through heppa filters which maintain a clean air flow free from insects and airborne debris. The challenge that this raise is that of temperature control within the growing room, as warm or hot air is drawn in during the spring and summer and cool and cold air during the autumn and winter. It is worth investigating installing heat exchangers to the inlet fan so that the internal temperature can be maintained at the optimum 15^{o} C. It has been demonstrated that the Mushroom Garden growing system works well in first world rural and urban settings. For it to work in developing countries and those areas of the world which have been devastated by natural disasters or conflict, however, the source of a reliable supply of electricity needs to be investigated. The energy input required is relatively small so that it would be worth investigating wind generated or photo voltaic generated electricity as an addition to the basic system.

Water

Capturing water from the growing rooms has provided anecdotal evidence that it nourishes or encourages growth in other plants, especially fruit and vegetables. This theory should be investigated further. It is not surprising as the soak off from the growing blocks contains proteins and polysaccharides from the mycelia networks. I have also noticed a perfusion of nettles growing from very old used substrate and in the vicinity of runoff water. This can be an indicator of high nitrogen content, which again could be the result of the natural breakdown of mycelium proteins. This could benefit other growing projects in the vicinity of the growing rooms.

Spent mushroom substrate.

Initial discussions with Dr Vera Thoss, an Environmental Chemist at the University of Wales Bangor, has indicated that the substrate may hold useful products that could be both extracted and isolated, including proteins, polysaccharides, and trace elements. If true, then the substrate can have added value as a source of natural products in addition to its mulching qualities. This requires further investigation and research.

Incorporating mushroom growing spaces into living spaces

In addition to communal mushroom growing in co-operation with other community-based growing projects, smaller scale growing systems could be integrated into the design of living spaces, using not only mushroom-growing spaces but hydroponics, permaculture, and micro-herbs to create a circular growing environment using spent substrate and water from the mushroom growing element.

8.3.2 Application

As demonstrated in this dissertation the Mushroom Garden system can be applied to many situations and is an excellent fit to the new economic models, and food security and sustainability strategies. Building on these issues, the system is a model of food production for the Post-Anthropocene era.

These aspects of application need to be developed further to achieve their full potential and models of different versions of the system need to be considered and developed for specific situations and applications. For example, the basic model, as described in the case studies, functions perfectly well in developed urban and rural communities. Urban locations are very promising with the emergence of community growing projects and city farms. Such developments need to be partnered by the local authority in terms of accessing substrate from municipal parks etc. The author is currently advising Cardiff City Council on establishing a mushroom growing facility alongside other food growing projects in a new build school that will unify two mainstream schools and one specialist school for children with learning challenge and disabilities which is an excellent opportunity to educate children about the production of nourishable food in their locality. Adaptations of the system could be incorporated into existing residential developments where there are redundant spaces e.g., basements or incorporated into new builds. The growing system but would it be as successful in developing economies, or within communities ravaged by conflict, natural disasters, or disease, as a means of rapid and safe nourishing food production? There would be challenges around supply of substrate and its preparation and supply of power in such circumstances. The system is a ready-made tool for educating people about where food comes from and teaching people to produce their own food cheaply and locally. Finally, an exciting direction of travel would be full integration of the system into co-developing communal living and food growing initiatives in future.

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11 APPENDIX

Appendix 1 - Tiny Tag Data

Appendix 2 - Vitamin D Results