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DESIGN FOR CONTROLLED ENVIRONMENT AGRICULTURE INSIDE AN AUSTRALIAN MAXIMUM-SECURITY PRISON: A RESEARCH FRAMEWORK

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ABSTRACT

This paper presents the framework for an early-stage PhD research project that aims to define and test the design requirements and the related feasibility of a Controlled Environment Agriculture (CEA) system concept within a maximum-security correctional center in Australia. The research seeks to develop new knowledge within the emerging field of CEA, drawing on the current understanding in the research literature and practice. Taking CEA technologies within the prison context creates new design challenges and opportunities that may lead to valuable knowledge relevant both within and outside prison systems. Situated within the industrial design discipline, the research and design process for developing the CEA system concept is an iterative, emergent process. The broad area in which this study is situated is in the field of CEA which can take the form of a vertical farm, where produce is grown vertically in warehouse-type shelves or on vertical panels. The unique aspect of this research lies in the application of a bottom-up consultative co-design process involving both prison administrators and inmate stakeholders. This project will contribute significant new knowledge using action research aimed at developing implementation guidelines for a CEA ecosystem that would supply fresh vegetables to inmates. Outside community groups may also benefit from this research.

KEY WORDS

Controlled environment agriculture; Prisons; Vertical farming; Human-Centered Design; Action research.

1. INTRODUCTION

The primary research question in this PhD study is: What CEA or vertical farm typology is the most suitable for reliable fresh food production in an Australian maximum-security correctional center? This prison CEA concept will be prototyped and tested during the second year of this study, and with the Macquarie Correctional Centre (MCC) in Wellington, New South Wales (NSW) being used as a case study.

Operated by Corrective Services NSW, MCC adopts the 'desistance theory', which is a criminology perspective that believes that positive life influences during rehabilitation and reintegration can help reduce deviance amongst prisoners (HOWARD & CORBEN, 2018; MCNEILL *et al.*, 2012; RONEL & ELISHA, 2010). MCC became operational in Feb 2018 and can accommodate 400 male inmates. It implements a structured day model of rehabilitation, which balances half-a-day

of paid work with half-a-day at programs or education, plus personal time for their own interests; this approach has had a positive impact on the mood and general wellbeing of inmates. MCC employs inmates in one of 8 industry business units – including furniture, food services, laundry, and heavy and light engineering – and delivers vocational education in several programs including business, carpentry, hospitality, automotive, and horticulture. Furthermore, MCC has an Inmate Development Committee (IDC) that serves as a forum for discussing issues of relevance to inmates and staff (NSW-ICS, 2020).

A secondary research question will be based on what is likely to be the most workable production system given the unique settings of the study. What system design, construction, cultivation, and management guidelines should be developed for maximum security correctional centers? The research will further consider other agricultural systems such as open-field agriculture, that could potentially be deployed in a maximum-security correctional center to complement CEA to balance out production costs.

The major objectives will be to engage stakeholders through a co-design process, with input from three stakeholder groups: the prison administrators; the Industry Overseers who are prison officers with backgrounds in skilled trades; and the inmates as end-users. A newly proposed system that inherently has reduced transport by using in-house production and less security scanning for the detection of contraband will also be considered. Reducing labor costs related to the scanning of incoming produce because fresh produce will be grown within the prison walls, will mean that contraband will no longer be able to enter the prison through this stream. These factors will become beneficial elements to the research. There are currently small-scale open agricultural fields within the prison at MCC that grow limited salad greens through summer months, but these are only used at present for education purposes. Interestingly these have been interrupted by a mice plague in Western New South Wales, as a result, crop yields have been significantly reduced. CEA can be used to support open-field agricultural production through slower growth during winter periods in cold climates for example so that the commercial supply of fresh produce is not interrupted. CEA, as it typically uses a closed environment, could also be used as a redundancy option so that commercial supply of fresh produce is not interrupted by vermin, pests, and disease.

Meal trays for lunch and dinner are currently produced either centrally, for the most part, using large commercial kitchens situated in the metropolitan area (Sydney NSW), or de-centrally as in the case of regional areas where some prisons act as food preparation hubs to prepare meals for distribution to nearby prisons. Each inmate receives daily the following: a shrink-wrapped breakfast pack consisting of tea, coffee, and sweetener satchels, 300ml light milk, a lunch meal tray (sandwiches and wraps are packaged in a plastic clamshell or vacuum-sealed shrink-wrapped pack), and an aluminum dinner tray which is typically delivered to accommodation pods as a heated dinner. Each prison typically has a kitchen/retherm unit for preparing basic cold lunch packs.

An experimentation base to be established through the prototyping stage will further inform the research. It is intended that the prototype will measure the growth rates and plant yield biomass for fresh produce such as salad greens and herbs on a per square meter rate. The benefit of prototyping is that once a per square meter yield is calculated it can easily be scaled to realize the potential to feed a larger group of inmates. Other factors to be measured include energy usage for air-conditioning, powering pumps for aeroponic irrigation, and water and fertilizer usage derived from a small aquaponics tank where live fish will provide the nutrient source. Finally, fish food will incorporate nutrients that will be required by plants on the farm and there will be an opportunity to also produce a nutrient-rich liquid derived from compost so that this can be incorporated into the irrigation tanks.

2. THEORETICAL FOUNDATION

The context of this research is multi-faceted. There are practical problems of nutrition, waste, and well-being within the prison system. These are documented in both the academic and practice literature (WILLIAMS *et al.*, 2009) and are the

lived experience of those within the system. At another level, there are the opportunities and value of emerging knowledge and technologies around Controlled Environment Agriculture (CEA) systems. CEA has the potential to change how, where and when food is grown in society. Finally, there is the context of design research practice and innovation. This research seeks to create knowledge and impact in the relevant research fields by applying design research methods and practices to explore the opportunities of utilizing CEA technologies within the prison context. Each of these contexts is outlined in the following sections.

2.1. The prison context

In CEA farming the environment is controlled for several reasons. Firstly, the temperature is controlled at a constant 25°C to ensure optimum growing conditions; additionally, carbon dioxide (CO₂) is pumped in at three times the atmospheric rate to significantly boost yield at certain stages of growth; and finally, irrigation systems water crops at a fraction of the rate of traditional agriculture. CEA systems are generally closed operations; this significantly eliminates pests and lowers the risk of disease. CEA predominantly uses a format of either (1) greenhouses, sunlight hours only, or sunlight plus LED lighting mimicking irradiation from the sun at night; or (2) Plant Factory using Artificial Light (PFAL) using LED lighting, that operate 24 hours per day. Emerging research points towards the advantages of a hybrid-style greenhouse-PFAL, as this can reduce energy inputs and thus operational costs. Hybrid CEA systems are used throughout the world so that fresh produce can be grown during sunlight hours organically and using LED lighting during nighttime hours; this helps to produce a more consistent yield and the produce that is grown has a similar appearance to that which people are accustomed to from store-bought vegetables. Because PFAL grows the produce under LED lights, the appearance and presentation of the vegetables are markedly different from that of field-grown produce, which can be off-putting for some, even though the products have a very similar taste profile and leaf texture to field-grown produce.

Improving food nutrition for inmates and reducing food wastage in NSW prisons is a problem. Typically, maximum-security prisons in NSW can house between 500 to 1000 prisoners and the prisons are spread geographically through a large state with significantly different climatic regions, and some regional prisons are located hundreds of kilometers from main cities such as Sydney. Currently, correctional centers in NSW do not provide inmates with fresh vegetables to their meal packs, mainly because the food preparation is centralized, and the food is transported long geographic distances throughout NSW. Food reheating for service to inmates is carried out via local prison retherm units where food is generally radiated to a significant temperature and at length, as per food safety requirements. Consequently, the nutritional profile of the food maybe less than that calculated and reported, due to nutrient losses during the delays between food production and service, long holding times, and subsequent re-heating, or re-use in cooking (WILLIAMS *et al.*, 2009). This results in a high amount of food wastage in the accommodation pods where the inmates live. Discarded dinner packs on any given night can be as high as more than half of the total of 25 inmates that live in the pod. Such observations are supported by several academic studies both in Australia (BLORE, 2011; WILLIAMS *et al.*, 2009) and internationally (DEATH & HORAN, 2018; SMOYER & MINKE, 2016). As such, the introduction of Controlled Environment Agriculture systems within prisons could be a cost-effective and environmentally responsible way to introduce fresh fruit and vegetables into inmate menus and diets. As the literature suggests, accessibility to fresh produce that is grown in a natural environment can enable a positive contrasting experience for inmates (TIMLER *et al.*, 2019).

In addition to wastage and environmental effects, food quality and management in prisons are related to a range of other outcomes. A literature review and case study by the World Health Organization (WHO) entitled, “Food systems in correctional settings” identified a range of health, cultural and behavioral outcomes (SMOYER & MINKE, 2016). Prisoners can gain excessive weight and suffer health-related issues due to poor nutrition whilst incarcerated that are associated with ongoing health costs. In a survey of NSW Correctional Centers, it was reported that 56% of men and 44% of women inmates were overweight or obese (INDIG *et al.*, 2010). Good nutrition derived from gardening and healthy food choices creates a culturally positive correctional environment when it comes to mealtimes. Better food

nutrition can also address feelings of worthlessness that inmates often experience, and by providing fresh produce there is an inherent positive psychological and physiological response. EVES & GESCH (2003) go as far as to suggest a relationship between dietary habits and recidivism, whereas WILLIAMS *et al* (2009) suggest there is a need for greater research and innovation about the delivery of fresh food in Australian prisons. This research study intends to use CEA to grow and supply fresh greens in NSW maximum security prisons.

Horticultural therapy could offer further therapeutic benefits to inmates, where nature can play a key role in achieving a healthy inmate population (MORAN & TURNER, 2019). A meta-analysis of research examining the effects of gardening, including horticultural therapy, on human health, provided robust evidence of positive effects, including improved physical and psychological wellbeing, sense of community, cognitive function, and reduced stress, anger, fatigue, depression, and anxiety (SOGA *et al.*, 2017). In the prison context specifically, MORAN & TURNER (2019) provide research suggesting that green environments and gardening have the potential to lead to a range of psychological benefits for inmates and staff. Gardening programs when used in a prison environment have also been found to improve mental health and aid in reducing substance abuse (TIMLER *et al.*, 2019). Gardening can also improve skills that are necessary for parolees for successful reentry back to the community (TIMLER *et al.*, 2019). Such benefits also included better social skills, enhanced self-esteem, and improved problem-solving and decision-making abilities (TIMLER *et al.*, 2019). In the NSW prison context, gardening may also provide inmates a more relaxed state of mind and give them some sense of purpose.

2.2. Controlled Environment Agriculture context

Vertical farms (VF) or plant factories can be divided broadly into three types; (i) Solar-type plant factories, also known as greenhouses; (ii) semi-enclosed plant factories using artificial light, also known as 'Greenhouses with Environment Control Systems (GECS), and (iii) completely enclosed Plant Factories using Artificial Light (PFAL) (KOZAI *et al.*, 2019). If managed correctly CEA can remove the risk of contamination and the risk of spread of disease in what are essentially sealed-off farm environments. Plant trays can be stacked in a vertical configuration and year-round constant crop production is possible using LED lighting schemes. Large scale production of leafy vegetables to more diverse crop types such as berries, eggplants, peppers is possible and experimentation growing grains is becoming a likely new avenue for CEA (KOZAI *et al.*, 2019).

Large scale vertical farms are springing up all over the World. Green Spirit Farms of New Buffalo, Michigan, is a single-story VF covering 3.25 hectares with racks stacked six high, it houses 17 million plants (MARKS, 2014). The farm was inspired by the long-term drought that has been affecting many parts of the United States. Even larger-scale farms have been built in Singapore, Japan, and Europe. Vertical farms use water conservatively and recycled grey water at a fraction of the rate used by traditional farms and are not at the mercy of weather-related variations in crop production (DESPOMMIER, 2011). Herbicides and pesticides can be virtually eliminated (DESPOMMIER, 2011). Vertical farming is less disruptive to native plants, vegetation, and animals, and farms can be located close to produce distribution points, minimizing carbon output from transport logistics. Additionally, agricultural technology including artificial intelligence and automation aimed at solving farm labor issues is being deployed to optimize yields. Current operators are even finding benefits in producing transplant stock.

Vertical farms offer great sustainability benefits by not disturbing balanced natural ecosystems and by using much less fertilizers that typically run-off land contours, polluting waterways. Traditional farming also comes with many occupational health and safety risks such as those through the operation of heavy machinery equipment, which can be mitigated significantly in a vertical farming environment (DESPOMMIER, 2011).

The framing theories involve drawing from existing literature that is based on therapeutical horticultural programs in prison environments, of which there are many international examples. The premise is to consider what fresh food production systems already exist in a prison context, for example, the successful horticulture program at Riker's prison

in New York (JILER, 2009) and as an overlay, examine commercial CEA systems that may be suitable in a prison context also. The framing theories further consider CEA and the role of plant factories in small communities. For example, PFAL is used for extracurricular education at Tomioka Elementary School in Fukushima while at the Sakakibara Memorial Hospital in Tokyo, recuperating patients grow vegetables in PFAL as horticultural therapy, and the harvest is then served to other hospitalized patients (TAKAGAKI *et al.*, 2016). Sustainability in operations and efficiencies in resource inflow and waste outflow will be considered in the study. Criticisms of plant factories and CEA will also be more broadly considered. A major barrier to the success of vertical farms is the high cost of start-up. This barrier also affects the proposed implementation of vertical farms in developing nations. There is a relatively low rate in terms of CEA uptake at a community level. Scandinavian and Asian countries such as Japan and Singapore are at present more suited to CEA because of shrinking agricultural land availability. Exploring and testing its use within prisons may help to identify and validate a model that could be used in communities also and provide the evidence base to make it more widely adopted. It is important to rely on analytical processes, see favorable and contradictory paths, examine the problem, and then create novel research beyond that which already exists. In developing the research, literature will be reviewed around specific Correctional Centre needs, identifying the gaps in current knowledge. Insights from the literature reviewed will be used to assist in the development of a set of requirements for the design of a system in the specific context of the Macquarie Correctional Centre.

2.3. Design research innovation context

Design innovation has a multitude of facets and contemporary interpretations. The UK Design Council presents innovation as the process of turning “ideas into value”, where design is “the connection between creativity and innovation” (DESIGN-COUNCIL, 2011). Giving form to abstract insights, prototyping, and visualizing disruptive concepts are all key contributions of design practice to the innovation process (DESIGN-COUNCIL, 2011). Design innovation capabilities fall into five main abilities: holistic view; how people give meaning to things; applying new technology; visualizing and materializing; and managing the design process (LANDONI *et al.*, 2016).

Furthermore, design thinking methodologies when coupled with innovation brings about new ways of designerly practice. What makes design thinking a social technology is its ability to counteract the biases of innovators and change the way they engage in the innovation process (LIEDTKA, 2018). What design practice innovation can achieve is to bring a much wider perspective. Design innovation and design thinking seek to sit with confounding problems in the design process and assist researchers to better understand contextual issues, resolutions, and future possibilities. Ultimately built environments such as those in CEA should, through the process of design innovation, understand and promote their communities’ culture in new ways too. A design innovation-led approach can assist in considering how the built environment feels for its varied users, in the context of staff, educators, and inmates alike.

2.4. The Design-for-Sustainability context

Drawing upon various theories in the text “Design for Sustainability,” (CESCHIN & GAZIULUSOY, 2019) such as Product-Service System design for sustainability (PSS), Design for Social Innovation (DfSI), Systemic Design (SD), and Design for Sustainability Transitions (DfST) will assist to situate the research not only from a product-centric focus but also from a system design perspective in the context of sustainability. It is important in the context of a prison environment to realize the complexities of a proposed system design from the technology/people dimension and the insular/systemic dimension. The former should seek to understand the role user practices and behavior play from a socio-technical viewpoint. The latter should seek to address Corrective Services Industries (CSI) internal issues relative to the conservative management approach for the implementation of new technologies and those that may be considered as disruptive, as is the case in CEA. CEA farming has a multitude of complexities, which go well beyond the typical scope for implementation of typical new business units in a prison setting, such as light engineering metal fabrication or furniture-making workshops that are staffed by Industry Overseers, with labor derived from inmates. Security

complexities in a correctional environment would need to allow for the acquisition and introduction of a range of new technologies and practices such as high-tech LED lighting, irrigation control systems, nutrient delivery systems administered by staff and inmates, and new safe working methodologies to manage such systems. To enable stakeholders to think beyond the technological complexities of any proposed new system design, CSI would need to consider the wider socio-economic systems (CESCHIN & GAZIULUSOY, 2019). This points towards the transformation of socio-technical systems through strategic design (CESCHIN & GAZIULUSOY, 2019). There has also been a shift from technocentric design to a human-centric approach, which designers typically refer to as human-centered design. This is an important consideration in the context of CEA operativity in correctional settings. There can be a relatively high turnover of inmates in a maximum-security prison with some inmates remaining at one prison for as short as 6 to 12 months when their maximum-security classification progresses to a medium or minimum-security classification. User-centered design needs to consider ease of use at a product design level and simplicity in operation and inmate training packages at a system level. Both need to be sufficiently comprehensive to ensure good operations of the CEA, but not be too complex needing lengthy training periods for users to adapt to.

Including a range of socio-ethical sustainability aspects in the research study such as meeting basic human needs, poverty alleviation, and improving labor conditions are an essential consideration in a prison context. The potential to improve inmate nutrition by enabling access to higher-quality fresh produce that is grown in a CEA environment can assist in reducing the poverty gap. The system design must also consider labor conditions and how the farms affect users from this viewpoint. A CEA environment that is rehabilitative will be an important consideration for this research study. How users are educated to improve rehabilitative outcomes and how labor conditions affect end-users in a future CEA environment, need also to be carefully considered and balanced. Furthermore, improving labor conditions should integrate weak and marginalized people to promote cohesion (CESCHIN & GAZIULUSOY, 2019). DfSI can potentially address the democratic empowerment of citizen-users, as well as the valorization of local resources and, more generally, community resilience. In this respect, prisoners can feel as though they are disempowered and that they have been excluded from society, so any future CEA farming system must also democratically empower inmates by enabling the opportunity through co-design to design the system and to have a voice in the running of the operation once the project is launched.

DfS at a product level needs to consider the various aspects of the product design to include energy and material efficiency and material recyclability and how these aspects complement each other (CESCHIN & GAZIULUSOY, 2019). In this regard, CEA is a relatively more energy-intensive method of farming compared to open-field agriculture and it can be driven using renewable energy sources. This entails a product design that feeds into a system design that has the potential to best conserve energy inputs in terms of the electricity that powers LED lighting through 24-hour plant growth cycles and the air-conditioning that keeps the growing environment at a temperature of 25°C for optimum plant health and growth. DfS is a framework that can be applied to this present research because it can be used as a tool to make sense of the complexities that characterize the DfS field (CESCHIN & GAZIULUSOY, 2019).

Innovative community practices, when well researched, considered, and implemented, can deliver a system that functions well and that has the potential to deliver a constant stream of fresh produce into inmate meal deliveries. Moreover, the scope of the design intervention from insular to systemic will become a foundational element of the research and co-design journey. The research innovation will need to incorporate interdisciplinary elements so that experts from trades that are found within a correctional center are harnessed for the prototyping process. The prison at which the case study is being undertaken has a functioning horticulture program that has recently begun offering horticulture traineeships to make the garden plot functional to produce fresh fruits and vegetables for educational purposes. This will further situate the research and it will be good to compare and consider how the horticulture garden may complement the implementation of a CEA vertical garden. Furthermore, prison complexes tend to be almost completely built out, so the compact nature of vertical farming is suited to well-established prisons with fewer opportunities to build large-scale agricultural gardens.

2.5. Justifications

We believe that this study is important for the following reasons:

1. Prisons historically have been large conservative organizations that are risk-averse particularly around issues of security and safety (STENSON, 2000).
2. Food and nutrition are often seen as secondary issues to safety and security, and gardens and agriculture have been viewed as security risks and additional complications to smooth operation.
3. Innovation does and has occurred with prison designers leading the design of ventilation systems; a particular example is through the work of Stephen Hales, the pioneer of ventilation (HARRIS, 1916).
4. Research on the value of good nutrition, horticultural therapy, and access to green landscapes in prison towards inmate well-being, prison culture and behavior, and food wastage suggest that these aspects are worth additional consideration.
5. Controlled Environment Agriculture systems may provide correctional institutions with an efficient, robust, and secure system of agriculture with a range of benefits and fewer risks.
6. Previously the introduction of new systems in prisons such as an agricultural system has been done ad-hoc. Little consideration has been given to the specific demands and considerations of the correctional environment. Taking a design approach to researching, designing, and testing a system that meets the specific challenges and opportunities of the prison context is a relatively unique and exciting opportunity for this research.
7. Controlled Environment Agriculture systems have not become mainstream in the community to produce food where people live, although its potential is evident. This research, through moving to design and validate the CEA system in prisons, could provide the evidence base for promoting the use of CEA in non-institutional contexts.

2.6. Research Design

The proposed methods will be to undertake a comprehensive literature review of CEA, using best practice contemporary international examples. In developing the research, literature will be reviewed around specific correctional center needs, identifying the gaps in current knowledge. Insights from the literature reviewed will be used to assist in the development of a set of requirements for the design of a system in the specific context of the Macquarie Correctional Centre. The prison on which the study is based has an Inmate Delegate Committee (IDC) which serves as a forum for inmates to propose initiatives that will improve the functioning of the prison. This process will also include a series of workshops or co-design sessions (SZEBEKO & TAN, 2010) utilizing the existing structure of the IDC. Information from the desktop research, stakeholder co-design sessions, and design explorations will inform a series of CEA system design proposals.

Co-design and human-centered design approaches that will be used need to consider ease of use at a product design level, simplicity in operation, and inmate training packages at a system level that are sufficiently comprehensive to ensure good operation of the CEA, but not be too complex needing lengthy training periods for humans to adapt to (IDEO, 2015). The co-design process will utilize a series of workshops or co-design sessions with stakeholders, including inmates, at the case study prison (SZEBEKO & TAN, 2010). The co-design sessions will consider open-field agriculture, as this method already exists at the case study prison, greenhouse production, plant factory production, and a hybrid plant factory production combining the features and benefits of a greenhouse and a PFAL at night to continue production. Co-design processes will include building empathy by ensuring that stakeholders and end-users -- including inmates, Industry Overseers, and Custodial Officers -- feel accepted and supported to be part of this consultative process, without judgment (IDEO, 2015). In considering human-centered design it will be important that inmates and Industry Overseers be allowed into the MCC food preparation and rethermalizing kitchen where the green produce will be incorporated into the prison lunch packs; this will enable them to gain better insights into the people who will be using the system and provide them opportunities to contribute their personal opinions and experiences (IDEO, 2015). Sharing the design

iterations at various stages of the research with stakeholders and inmates will further build empathy into the research, design, and innovation process (IDEO, 2015).

So that innovative solutions can be developed it will be essential to get to know the different stakeholders and end-users and consider what their respective workplace learnings are and then apply this to the unique setting which exists in the context of a correctional environment; this will keep the research focused and grounded (IDEO, 2015). Additional research will include surveying the IDC and relevant staff within CSI. The qualitative and quantitative data from these surveys will be analyzed around relevant themes and used to refine and create recommendations around a viable model of CEA with the prison context. Building empathy will involve observing survey participants, engaging, and immersing with users to learn their values (DOORLEY *et al.*, 2018). Insight statements into opportunities for design will be achieved by reframing them as “How Might We” questions (IDEO, 2015). Surveys will be constructed using 3 criteria: desirability, feasibility, and viability (IDEO, 2015). The qualitative and quantitative data from these surveys will be analyzed around relevant themes and used to refine and create recommendations for a viable model of CEA within the prison context.

Importantly, being mindful of the distinction between the roles that I will play both as a facilitator and as an expert designer will help to better guide the co-design processes (SELLONI, 2017). The more that co-design processes evolve, the more important it is for expert designers to consider the responsibility they have in guiding and in defining the role they must play (SELLONI, 2017). In essence, there is a distinction between a community of citizens using their natural design capacity to solve daily design problems, and designers applying a specific set of methods and tools (SELLONI, 2017). Designers should have their view of the world and realize how the role of the designer as a facilitator is best conciliated as being a “bringer of visions and proposals” (SELLONI, 2017). It will also be important to learn how to facilitate discussions to acknowledge people’s expressions, crucially to lead, guide, and provide frameworks to encourage creativity through the co-design sessions (SELLONI, 2017). Regarding facilitation, it will be important to become both facilitator and provoker, where ideas that are co-created become more visible and assessable and to stimulate the group to bring about original visions and proposals through visioning (SELLONI, 2017). Bringing about visions and ‘making together’ have characterized the role of designers within a community (SELLONI, 2017).

Once the processes of empathizing and ideating have been completed, prototyping will begin and involve testing the product design and system design to reveal and evaluate operational mechanisms, the prototyping process will essentially become the main research method (IDEO, 2015). Co-design processes involving developing empathy for stakeholders and inmates will allow questioning of assumptions, which may lead to inspiring new solutions (SZEBEKO & TAN, 2010). The prototype will be constructed as a metal fabrication in the light engineering fabrication workshop at MCC. The produce to be trialed will involve varieties of lettuce (*Lactuca sativa*) and a variety of herbs for use in cooking in the inmate kitchenettes. The ethics clearance required for the study will most likely relate to anonymous surveys and voice-recorded anonymous discussions from stakeholders that will be deleted after the discussions are transcribed.

The prototype to be constructed at the case study prison will include lighting, air-conditioning, and irrigation. The testing of the prototype will allow us to iterate and make design amendments as necessary. Data analysis techniques will involve fresh food production using the designed prototype (a possible growing area of up to 5m²) and then averaging production at a per square meter rate, as this is easily scalable to an entire prison. The irrigation method will consider an aquaponic tank being used to provide nutrients to the aeroponic system. The case study prison is also experimenting with compressing the green vegetable waste products from the kitchen to extract a liquid plant feed and it may be possible also to experiment using this liquid nutrient in the prototype. The metrics base will be to consider fresh food production relative to a pod of 25 inmate residents, which is typically the situation where the case study will be undertaken. The prototype will be scaled according to the research funding obtained. Ethics protocols will consider human research both at the staff level and at the inmate level. The ethics clearance required for the study will most likely relate to anonymous surveys and anonymous administrative staff discussions.

In addition to co-design methodologies, action research (AR) methods have been chosen in this study because they meet the high levels of academic rigor that are demanded at this level of study. Action research is future-oriented, collaborative, agonistic, implies system development, situational; it also generates theory grounded in action, so it is well suited to this community-based systematic design research project (GAMMAN & THORPE, 2018; SUSMAN & EVERED, 1978). AR can be applied to construction-type projects because it is seen as being predictive, future-focused, and it encompasses the needs of both academia and industry simultaneously. The study will incorporate AR methodologies to identify certain standards of judgment so that data can be turned into evidence (GAYÁ WICKS *et al.*, 2008). The processes involved in doing this include sorting and categorizing the data, analyzing the data for meanings, identifying criteria and standards of judgment, generating evidence (GAYÁ WICKS *et al.*, 2008).

2.7. Proposed Methodological Map

The research methodology involves 3 distinct lenses that overlap each other, with CEA located centrally within these spheres (Figure 1). In terms of the research journey, designerly practice will guide the co-design, action research, product design, system design, and design for sustainability processes. In the following diagram, the bottom lens represents the methodology, whilst the remaining lenses contextualize the research areas that form the elements of the conceptual framework for the study. The overlapping lenses consider positive outcomes for the research study, with the central overlap representing CEA and the research gap.

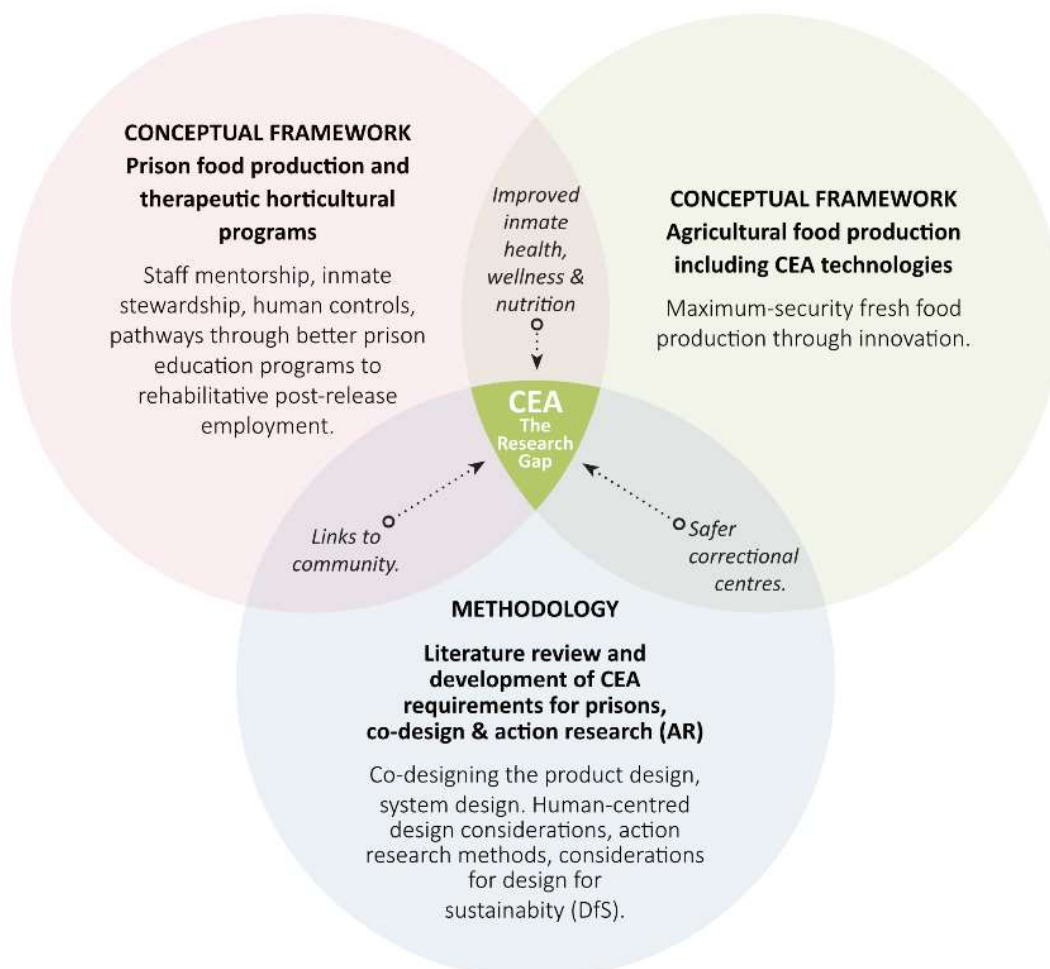


Figure 1: Overview of the study with three distinct lenses and overlapping outcomes, culminating with CEA and the research gap as the central element of the dissertation. SOURCE: Shelden Vaughan.

2.8. Data Sources

The primary quantitative data to be used in this study will be derived from the prototype. A series of growth production rate experiments will be undertaken over several months. The prototype will also be used to evaluate lighting efficiency, irrigation (using aquaponics on a small scale), and energy costs. Data will be obtained from literature as there is currently much work being done in the CEA field involving everything from production rates, to taste and nutrition profiles of produce, to the technical and technological aspects of production.

The sort of data needed to answer the research questions will be obtained through investigating studies in the field of vertical farming and plant factory production systems and through qualitative and quantitative research conducted within the prisons as part of this project. There are several large-scale research groups internationally that are gathering and sharing data related to the design, operation, and performance of vertical farm systems (KOZAI *et al.*, 2019). This project will also include the collection of qualitative and quantitative data at various stages.

Through the co-design process, consultative surveys will be gathered and will assist in framing the prototype and developing the commercial plant factory as a longer-term concept proposal for CSI. In this sense the human input will be monitored, data will be obtained and related to human-centered design outcomes (IDEO, 2015).

Action research in context will enable data to be gathered formally. Monitoring of the knowledge transfer processes developed through co-design sessions will also create data points for the study (SELLONI, 2017). The survey design for this process will be guided using literature, being mindful that our personal experience does not always guarantee knowledge about the optimal choice (OBERSKI, 2015). What is considered as “best practice” varies among people and organizations (OBERSKI, 2015). Data will be collected from co-design workshops with the stakeholders during each stage of the research and this will include identification of the requirements for CEA in the case-study prison, aimed towards the development of the prototype. This will include formal structured interviews of current administrative staff from CSI who are highly experienced in maximum-security food catering operations and potentially companies and researchers working in the field of CEA. Data from each stage of the research including the development of requirements, development of prototypes, and the final comparative study of the prototypes will be analyzed using qualitative and quantitative methods. Qualitative data will be coded and grouped to develop core themes and identify key insights.

The data stemming from co-design group sessions and individual interviews with participants will be analyzed initially to reveal common themes and then categorized by conversations with prison administrative staff and conversations with prison inmates (GAYÁ WICKS *et al.*, 2008). Analyzing the data for meanings will involve understanding what the participants are saying, considering what things are worthwhile and what is of value (GAYÁ WICKS *et al.*, 2008). Understanding the difference between standards of judgment and criteria is an important distinction. Criteria take the form of words and phrases that are used as markers of performance (GAYÁ WICKS *et al.*, 2008). It will then be important to select from the data, pieces of data that carry a special meaning to justify and test my provisional claim and to make a realization of my values that are considered as good in practice (GAYÁ WICKS *et al.*, 2008).

2.9. Research Timeline

The timeline for the study is shown below across 3 years.

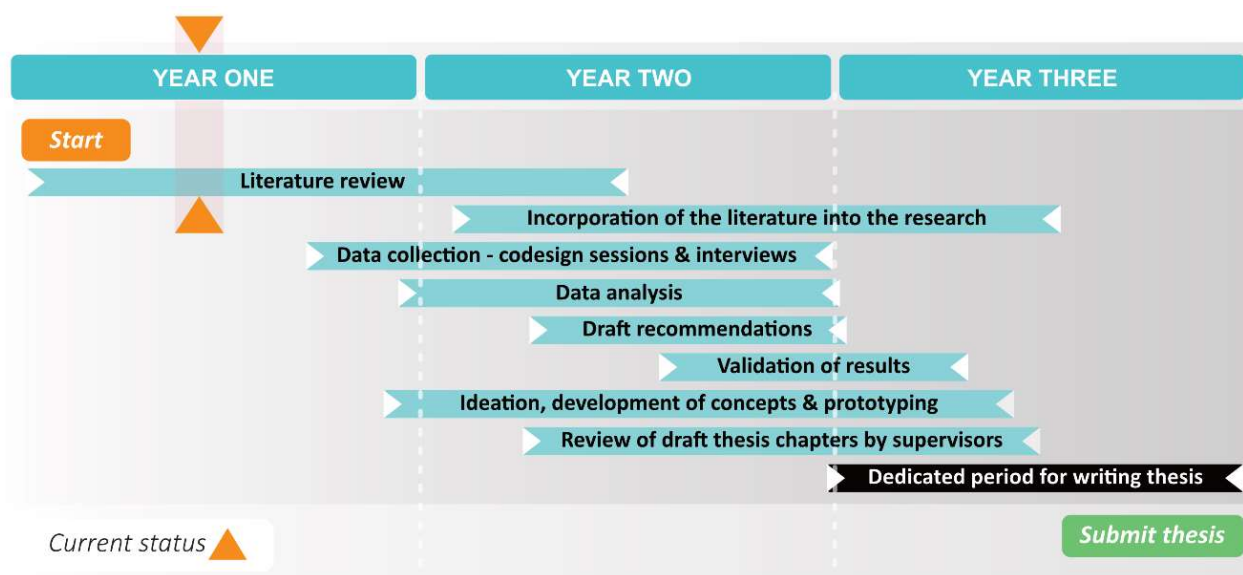


Figure 2: An overview of the Timeline for the research project. SOURCE: Shelden Vaughan.

3. DISCUSSION & CONCLUSION

This study will contribute towards the development of a comprehensive set of guidelines for Australian maximum-security correctional centers for the best practice implementation of a CEA ecosystem for fresh food production. The significance and potential impact of the research is that the system design will create a whole new way of supplying fresh produce to inmates. This can contribute towards making prisons safer by containing contraband because fresh produce will not come through normal inward channels via transport from external farms. Improving inmate health and wellness is important, given the incidence of health-related conditions such as diabetes for example that are derived from poor nutrition. The dominant question will always be centered around, “Is it worth the investment?” This could be evaluated from health, social wellbeing, economic and other aspects. Further to this question another will be posed related to the stakeholders; “Do the stakeholders understand the value proposition and will the CEA be reliable enough to provide consistent yields and feed the inmate population?” Finally, of further significance will be creating stronger rehabilitation rubrics, although this will not be measured in the study, aimed at providing more positive benefits back to the community that parolees will once again join, through inmates gaining education and entrepreneurial skills in the field of CEA and allied fresh food production (GAMMAN & THORPE, 2018). This project is in its early phase and is due to be completed in Jan 2024.

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