Chapter 2
Integrated Urban Controlled Environment Agriculture Systems

K.C. Ting, Tao Lin, and Paul C. Davidson

Abstract Controlled environment agriculture (CEA) has evolved from very simple row covers in open fields to highly sophisticated facilities that project an image of factories for producing edible, ornamental, medicinal, or industrial plants. Urban farming activities have been developed and promoted as a part of the infrastructures that support residents' lives in high-population-density cities. Technology-intensive CEA is emerging as a viable form of urban farming. This type of CEA is likely to include engineering and scientific solutions for the production of plants, delivery of environmental parameters, machines for material handling and process control, and information for decision support. Therefore, the deployment of CEA for urban farming requires many components, subsystems, and other external influencing factors to be systematically considered and integrated. This chapter will describe high-tech CEA as a system, provide a systems methodology (i.e., the concept of automation-culture-environment systems or ACESys), propose a decision support platform (i.e., the concurrent science, engineering, and technology or ConSEnT, computational environment), and identify challenges and opportunities in implementing integrated urban controlled environment agriculture systems or IUCEAS.

Keywords Urban agriculture • Controlled environment agriculture • Systems integration • Systems informatics and analytics • Decision support

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2.1 Introduction

Since the beginning of human civilization, protective structures for plant cultivation have been developed with increasing sophistication, ranging from growing plants under simple covers to producing large-quantity and high-quality crops within precisely controlled environments. The analysis, planning, design, construction, management, and operation of high-tech controlled environment agriculture (CEA) for plant production require multidisciplinary expertise. Plant science and engineering technology, as well as their interrelationships, are the foundation for technically workable and economically viable high-tech CEA. Today, there is a wealth of knowledge for designing and managing plant-based engineering systems, i.e., phytomation systems (Ting et al. 2003).

It is commonly known that plants require air, light, water, and nutrients while exposed to appropriate ranges of temperature and relative humidity, to effectively grow and develop. The extent of growth and development varies with different plants when subjected to different combinations of the factors above. Plant scientists have, for many years, investigated the fundamental phenomena of plant physiology, photosynthesis, pathology, etc. Horticulturists have explored ways to cultivate and produce plants to satisfy certain purposes. Engineers have developed methods and equipment to create and deliver growing environment, support structures, material handling devices, and logistics operations to enable plant production at various scales. As mentioned above, these expertise need to be integrated in order to result in functional (and preferably optimized) CEA systems. It is also important to consider social, economic, and surrounding environmental conditions for successful "commercial" scale CEA systems (Nelkin and Caplow 2008; Despommier 2010).

It is predicted that, by 2050, the global population will exceed nine billion people and more than 70 % will live in high-population urban areas (United Nations 2014). Food security, in the context of availability, accessibility, utilization, and stability, is expected to be a daunting challenge, especially for the constant supply of fresh vegetables. Energy security and water security are strongly linked with food security. They have to be addressed in an integrated fashion. Therefore, the nexus of food-energy-water plays a very important role in urban food systems. CEA, especially in the form of plant factories (a.k.a. vertical farming), is well positioned to be part of urban food systems and deserves to be systematically analyzed within that context.

Systems analysis is a methodology that emphasizes the interfaces among the components of a system to investigate how components should work together. It is an important task to determine whether it makes sense to integrate interrelated components to achieve predetermined overall (i.e., system level) goals. The analysis can also help identify ways to resolve the interconnectedness of components and explore ways to improve the overall performance or derive the best system design and operation scenario under various constraints (Ting 1998). Systems analyses have been carried out by CEA researchers and practitioners in various ways. The development of information and computational technologies has brought exciting opportunities for advancing our ability to conduct analyses on CEA systems that are with increasing complexities.

2.2 Recent Evolution of CEA

Figure 2.1 depicts the technological and functional evolution of CEA over the past 50 years. Light, temperature, air relative humidity and composition, plant nutrition, etc. are critical environment and physiology factors that determine the plant productivity and quality. Controlled environment, from protected cultivation and greenhouses to sophisticated, environmentally controlled plant factory, aims to provide extended range of microenvironmental conditions to support plant production either during the times when the natural environments are not conducive to plant growth or throughout the year.

2.2.1 Protected Cultivation

Protected cultivation refers to simple covers over plants in the production fields without advanced environmental control systems. They are normally seen in the forms of anchored plastic mulch, floating mulch, and low tunnels (Baudoin 1999). The purpose of protected cultivation is to improve the plant microenvironment for enhanced crop productivity in open fields. The key benefit of protected cultivation is to provide relatively low-cost crop protection from direct impact by the natural elements, such as frost and freezing. It can also promote water use efficiency and reduce risks of damages from insects, weeds, and other predators. There has been a continuing expansion in crop production areas utilizing protected cultivation, as well as an increase in its application in higher-value vegetable crops and flowers/ ornamental plants (Wittwer and Castilla 1995). The comparative advantages derived from protected cultivation were the driving force for researchers and farmers to explore the technical workability and economic viability of creating and investing in increasingly sophisticated operations, equipment, and facilities for plant production.

2.2.2 Greenhouses

Commercial greenhouses started to emerge when better and larger enclosing structures and more elaborate plant growing configurations and devices were added to the original concept of protected cultivation. The larger structure of greenhouses allows sufficient vertical and horizontal spaces for workers to perform

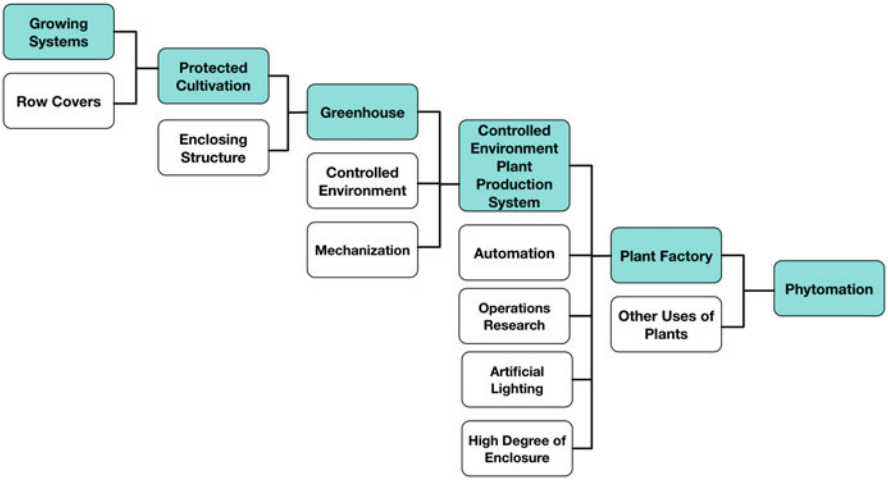

Fig. 2.1 From protected cultivation to phytomation

plant culture tasks and for taller plants to grow upright. The early form of greenhouses had a limited indoor environmental control ability; however, it was capable of providing much better modified environments for plants to produce a profitable yield during unfavorable outdoor conditions. The greenhouse's ability to control the environment under its enclosed structure allowed for an increased productivity of plants and human workers in addition to other direct benefits to plants and workers (Wittwer and Castilla 1995). Many growers started to improve upon the low-cost simple greenhouse structures that had poor environmental control and did not allow plants to reach their potential yield and quality (Baudoin 1999). Heating, cooling, ventilation, lighting, and CO_2 enrichment are key environmental control considerations within a greenhouse. Among them, better temperature controls, especially by heating, were the initial purpose for growers' adoption of greenhouses. The details of functional characteristics and design requirements of greenhouses have been reviewed by von Elsner et al. (2000a, b).

2.2.3 Controlled Environment Plant Production Systems (CEPPS)

Building on the advantages of greenhouses, additional investments were made to add more technologies, including automated indoor environmental control and mechanized plant growing and handling equipment. The impact of the entire production facility to the outdoor environment also started to attract interest. The concept of environmental friendliness of enclosed plant production operations became an important topic in the late 1980s and early 1990s. The increase in complexity of biological, physical, and chemical requirements for efficient plant growth and development, combined with the added constraints of social acceptance and government regulations, started to require plant producers to be skillful in the management aspect of their operations. The term “controlled environment plant production systems (CEPPS)” emerged as a more appropriate description for “advanced greenhouses.” CEPPS is a form of controlled environment agriculture (CEA). CEA implies that it may include the production of livestock or fish. In recent years, “plant factory” and “vertical farming” have been used to represent certain forms of CEPPS that are particularly suitable as a part of urban agriculture and food systems.

2.2.4 Phytomation

CEPPS may be used for purposes other than producing plants for commercial markets. One example is phytoremediation processes for treating contaminated water within a controlled environment. This system has a similar form as a hydroponic plant growing system; however, the functional objective is reversed. Instead of supplying nutrient solutions to grow plants as a marketable product, it uses special types of plant to “rhizo-filtrate” contaminated water into clean water (Dushenkov et al. 1997; Fleisher et al. 2002). The cleaned water is the product of a phytoremediation CEPPS. Another example is the crop production unit within an advanced life support system (ALSS) for human long-duration space exploration. The crop production unit is similar in concept of a plant factory or vertical farming operation; however, the purposes are more than providing food for the crew members. It also participates in cleaning the recycled water and converting CO_2 to O_2 in the atmosphere within the ALSS (Kang et al. 2001; Rodriguez et al. 2003).

The added functional dimensions of enclosed plant production systems called for the need of an effective methodology for systems analysis and integration. An automation-culture-environment oriented systems analysis (ACESys) concept was proposed (Ting 1997). A term “phytomation” was created to capture this phase of evolution to describe all plant-based engineering systems (Ting et al. 2003).

2.2.5 Plant Factories with Artificial Light

The term “plant factory” has been used, mostly in Asia, to describe a commercial plant production facility that has similar operational principles as a typical industrial manufacturing facility. It typically has a very structured interior configuration with carefully designed processes for handling plants through their various stages of growth and development. The environmental and plant support parameters, such as temperature, relative humidity, light, CO_2, and nutrient solution conditions, in the facility are controlled within predetermined target ranges (Watanabe 2011; Goto 2012). Many plant factories are equipped with high-tech sensing, computing, process control, and automation devices for plant, nutrient solution, and environmental monitoring, as well as task planning and execution. In addition, some plant factories also have automated or mechanized systems for manipulating and transporting plants and assessing plant quality. Due to the relatively high financial investment required for plant factories, they are designed and managed to achieve very high space and resource use efficiency and to produce predictable high quantity, quality, and market value crops.

There are three options for lighting source for plants: (1) 100 % sunlight through translucent roof and/or walls, (2) 100 % "artificial" light from electricity-powered illumination devices, and (3) the combination of the two. The second type is called "plant factory with artificial light" (Kozai 2013). It allows the facility enclosure to be constructed in a way to minimize the influence of external environmental conditions. This provides the plant factory manager a better control of crop production operations. However, due to the total dependency on electricity for providing light energy, the requirements and cost-effectiveness of lighting devices for plant growth and development need to be carefully understood, selected, and operated.

The commonly used artificial light sources include high-pressure sodium lamps, fluorescent light tubes, light-emitting diodes (LEDs), etc. In recent years, LEDs have gained a significant amount of attention in the research community, CEA industry, and lighting device manufacturers. There are a number of advantages of LEDs as compared to the other forms of lighting equipment. LEDs have the potential of reducing the electricity costs from efficient conversion of electric power to targeted light wavelengths usable by plants, as well as from reducing cooling costs due to the lower thermal energy generation. The LED's compact design also allows its placement near the plants, which enables the configuration of multiple plant production layers, stacked vertically, within a plant factory facility. The high capital and operating costs of LEDs continue to be a high-priority research and development subject for future plant factories. This book will provide a comprehensive treatise of the state-of-the-art plant factories with artificial light and LEDs.

2.3 CEA's Role and Participants Within Urban Food and Agriculture Systems

Agriculture for food production as part of modern urban infrastructures has gained considerable attention in recent years (Pearson et al. 2010). There are many reasons why urban agriculture is desirable or even essential. Locally grown food, especially fresh vegetables, is not readily available in many metropolitan areas with high population densities. Fresh produce that travels a long distance to reach consumers in big cities requires high fuel and logistics costs and is prone to quantity and quality losses. Community-based food production systems are expected to contribute to the establishment of smart cities and healthy cities. CEA in or near urban areas, as part of urban food systems, can provide a reliable and safe food supply year-round (Despommier 2010). It may also enhance economic and social development of the cities. Its impact to the vegetable supply chain has been a research topic of some researchers (Hu et al. 2014).

There has been accelerated development in commercial CEA applications in the form of plant factories in East Asia, most noticeably in Japan and Taiwan. The major players include research and educational institutions, various levels of governments, real estate developers and builders, construction companies, heating/ventilation/air conditioning industry, electronics industry, supermarkets, restaurants, consumers, media, etc. This signifies the emerging opportunities for a wide range of businesses, as well as the unique challenges in how to simultaneously make things work better and make things work together.

2.4 CEA's Functional Components and Subsystems

Innovations in greenhouse engineering and horticulture have provided technical advances that have helped to bring about the state-of-the-art facilities and operations in CEA. The innovations are the results of responding to the need for improving CEA operations, as well as to the anticipated strategic changes in production systems. Operational factors that influence CEA systems include consumer preferences, market accessibility, labor availability, energy cost, logistics, etc. Factors that have strategic implications have mostly resulted from broader, regional issues such as environmental impact, product safety and consistency, and consumer demand (Giacomelli et al. 2008). A more detailed description of the controlled environment plant production system indicated in Fig. 2.1 is shown in Fig. 2.2.

The growing systems are the center stage of a CEPPS (i.e., CEA). It supports the plants (i.e., crops) that are established, grown, and harvested as the marketable product. Attention is normally paid to ensure plant quality by exposing the plants to appropriate environment, substrate, and nutrients. Plants at certain stages of production will need to be physically supported, manipulated, and transported either manually or by machines. There are many forms of external structures that can be used to enclose the entire production area and space. The most common glazing materials that allow sunlight transmission are glass panels and film and rigid plastics. Plant factories with 100 % artificial light sources normally use opaque construction materials. This presents an opportunity to have the walls and roofs well insulated for easier inside temperature control and better energy conservation. Some plant factories are situated inside a commercial building and may coexist with business and residential areas.

It is important to understand how the surrounding environmental factors impact the growth and development of the plants. In designing and operating a CEA system, it is also necessary to know how to deliver the desirable environmental

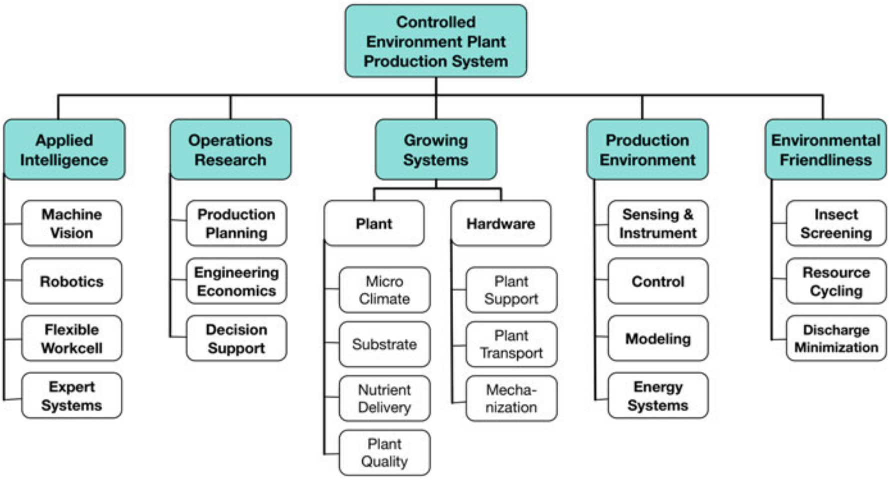

Fig. 2.2 Functional components of controlled environment plant production system

conditions. Therefore, within a CEA system, it will be ideal to have the capabilities of providing heating/cooling/ventilation, controlling relative humidity, enriching CO_2, and supplementing/adjusting lighting. The actions taken to activate these capabilities are sensing, data acquisition, and feedback/feedforward/model-based control. In many parts of the world, energy consumption for heating and/or cooling CEA environments is a significant portion of the initial and operating costs. Therefore, there have been a substantial amount of studies on utilizing energy from alternative or renewable sources to replace the heat and power derived from fossil-based fuels.

Recent developments in information technologies and mechatronics have worked their way into CEA system management and operations. Commonly seen applied intelligence includes computer vision-supported machine guidance for materials handling and watering, as well as plant quality evaluation and sorting. This added capacity also allows the automation of production planning and adaptive control of cultural tasks and environmental factors. A number of innovative ideas for minimizing impacts to the external environment have been put into practice, which include insect and disease screening, discharge minimization, and resource recycling.

2.4.1 CEA as Integrated Systems: An ACESys Model

So far, we have used the term “CEA system” without providing a systems approach for analyzing the system. We will start to bring that concept into our discussion. Within the context of this chapter, the technologies and knowledge bases needed for delivering a successful CEA system are in the areas of automation, culture,

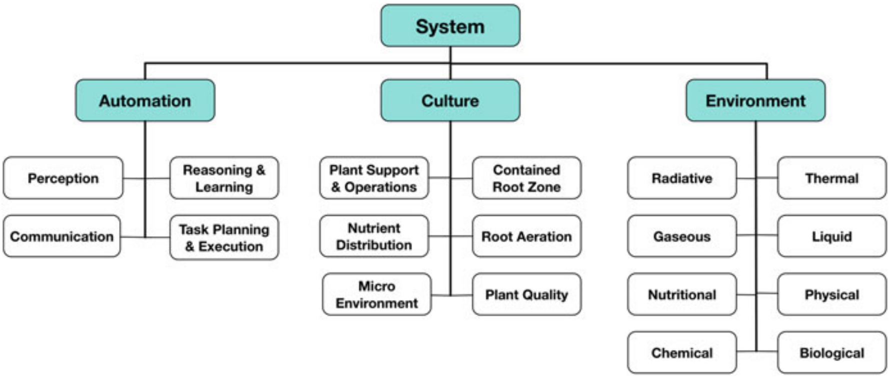

Fig. 2.3 The ACESys concept for CEA systems

environment, and systems (ACESys for short). Figure 2.3 is another version of Fig. 2.2, with an emphasis on the systems concept. Here are the brief descriptions of A, C, E, and Sys:

Automation deals with information processing and task execution related to a system's operation including the capabilities of perception, reasoning/learning, communication, and task planning/execution.

Culture includes the factors and practices that can directly describe and/or modify the biological growth and development of plants.

Environment encompasses the surroundings of plants, which consist of climatic and nutritional, as well as structural/mechanical, conditions.

Systems analysis and integration is a methodology that starts with the definition of a system and its goals and leads to the conclusion regarding the system's workability, productivity, reliability, and other performance indicators.

A plant factory with 100 % artificial light sources is a "closed" plant production system that provides a high level of control over plant production. This form of "closed" system exhibits the integration of automation, plant cultural requirements, and environmental control. An object-oriented approach guided by the ACESys concept may be taken to analyze plant production systems. The purpose was to develop a set of foundation classes that could be used to effectively describe the components of closed plant production systems. For example, eight foundation classes could be developed as the result of the object-oriented analysis, namely: Automation, Culture_Plant, Culture_Task, Culture_Facility, Environment_Rootzone, Environment_Aerial, Environment_Spatial, and Shell. Every class may contain key attributes and methods that provide appropriate systems informatics and analysis utilities for the systems under study. A computer model developed based on these classes and attributes would be capable of calculating crop yield, inedible plant material, transpiration water, power usage, automation, labor requirement, etc. over time for various crop mixes and scheduling scenarios (Fleisher et al. 1999; Kang et al. 2000; Rodriguez et al. 2003).

This modeling methodology can be modified into another example of analyzing CEA systems. Ting and Sase (2000) developed the following foundation classes, using the ACESys concept: (I) Category of Automation – Class_Perception, Class_Reasoning/Learning, Class_Communication, Class_Task_Planning, and Class_Task_Execution; (II) Category of Culture – Class_Crop, Class_Cultural_Task, and Class_Cultural_Support; (III) Category of Environment – Class_Environment_Structure and Class_Environment_Equipment; (IV) Category of System Level – Class_System_Requirement; and (V) Category of Result of Analysis – Class_Model_Output. The information flow pattern among the classes is depicted in Fig. 2.4. The arrows connecting the class objects indicate the key aspects of compatibility among the objects to be investigated. For example, perception class objects need to be capable of measuring the status and/or activities of class objects of environment_equipment, environment_structure, culture_task, and crop. Based on the signal from class object task_planning, the task_execution class objects must issue commands to activate class objects of environment_equipment and culture_task. The physical and functional compatibility among class objects is essential in ensuring the technical workability of the entire CEA system. Furthermore, the information is helpful in improving (or optimizing) the system design. The above examples represent very simple abstractions of CEA systems. The same methodology may be scaled up to represent CEA systems at a more sophisticated level.

2.5 Intelligence-Empowered CEA

Modern agriculture is an intelligence-empowered production system that requires capability for information collection/processing and decision-making, mechatronic devices for sensing, controls and actions, and ability to synergistically integrate components into functional systems. CEA is no exception. Its activities require actions taken by the growers in physical spaces, such as the core activities mentioned in Fig. 2.5. Ideally, these actions should be supported and guided by the intelligence resulted from analyses in the information space. An information system consisting of effective contents and efficient delivery methods will be very valuable in empowering growers in their decision-making.

Information technologies that can potentially provide the needed intelligence to agriculture include (1) *perception* using sensing and data acquisition/management technologies; (2) *reasoning and learning* involving mathematical, statistical, logical, and heuristic methodologies; handling of incomplete and uncertain information; and data mining; (3) *communication* by considering the contents, sources and recipients, and delivery platforms including wired, wireless, local area network, wide area network, Internet, and mobile technologies and devices; (4) *task planning and execution* that involve control logic, planning of physical tasks, intelligent machines, robotics, and flexible automation workcells; and (5) *systems integration* to provide computational resources and capabilities of systems informatics,

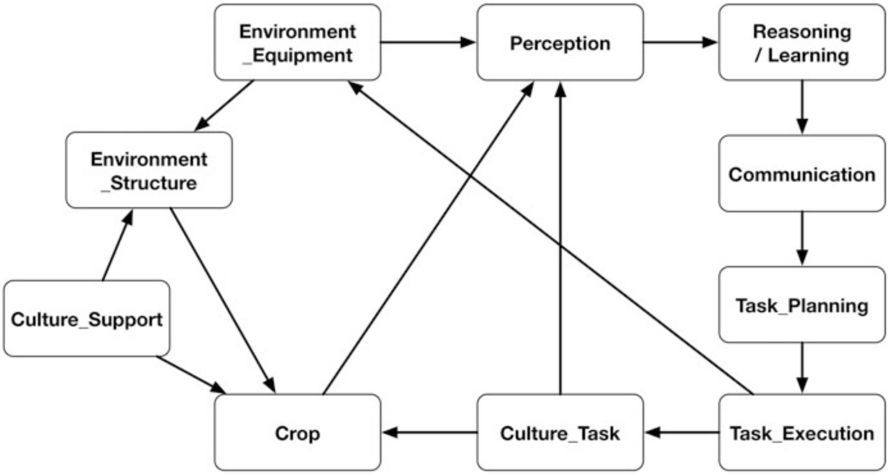

Fig. 2.4 Information flow diagram of ACESys objects for a CEA system

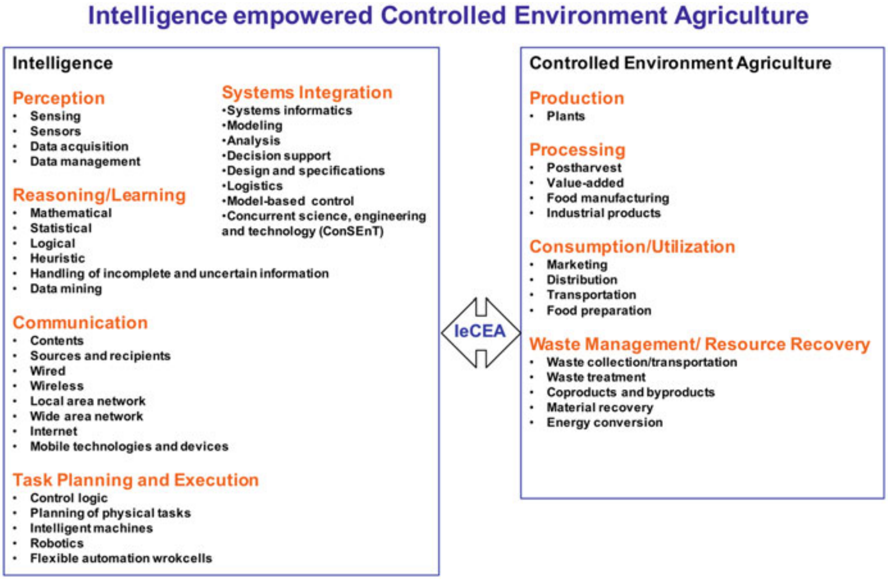

Fig. 2.5 Intelligence-empowered controlled environment agriculture (IeCEA)

modeling, analysis (simulation, trade studies, parametric analysis, life cycle analysis, optimization, etc.), decision support, design and specifications, logic and model-based control, and concurrent science, engineering, and technology (ConSEnT).

A substantial amount of work has been done in adding certain kind of intelligence to specific CEA tasks. Commonly seen studies have been in applying reasoning algorithms to develop control logic for controlling production environment within CEA. Related work may include sensing and communication technologies. Kolokotsa's team and Park's team have developed methodologies to monitor and control key environmental parameters, such as temperature, relative humidity, CO_2 concentration, and illumination based on Zigbee and Bluetooth wireless communication technologies (Kolokosta et al. 2010; Park and Park 2011). Mathematical models have been developed for predictive simulation and/or controlling CEA environment (Fitz-Rodriguez et al. 2010; Ishigami et al. 2013). Some models were developed specifically for controlling the cooling (Villarreal-Guerrero et al. 2012) and heating (Reiss et al. 2007) of greenhouses. van Straten's team developed a greenhouse environmental control strategy focusing on an optimization principle of making efficient use of the resource to maximize the economic return or minimize the cost of production (van Straten et al. 2000).

Another area of empowerment of CEA production operation has been the use of machine vision capabilities for quality sorting of plant materials and/or task guidance of automated machines (Tai et al. 1994; Kondo and Ting 1998).

2.6 CEA Systems Informatics and Analytics

As described above, opportunities exist for creating intelligent CEA systems enabled by systems informatics and analytics (SIA) concepts. The positive driving forces are the wealth of CEA-related domain knowledge; higher technology readiness level; available information technology, mechanization, and computer modeling capabilities; effective communication systems and computational platforms; improved economic picture; better market acceptance; potential spin-off technologies; ability to implement emerging technologies; etc.

The intelligence resources needed are informatics, computer modeling, systems analysis (in the forms of methodologies and tools for computation, simulation, and optimization), and actionable decision support (in the forms of analytics and consultative advices). All of these need to take into consideration of content, reasoning, audience, delivery, and action.

Systems analysis is a well-studied science that includes problem-focused and conclusion-targeted analytical algorithms and computational tools. One proven procedure for carrying out systems analysis is as follows:

1. Define system's scope and objectives.
2. Identify system constraints.
3. Establish indicators of success.
4. Conduct system abstraction.
5. Obtain data and information.
6. Handle uncertainty and incomplete information.
7. Incorporate heuristic and fuzzy reasoning.
8. Develop system model.

9. Verify and validate model.
10. Investigate what-ifs.
11. Draw conclusions.
12. Plan and execute actions.
13. Communicate outcomes.
14. Continuous monitoring and improvement.

The 14 steps are normally done in a sequential manner with the possibility of some steps being omitted or repeated depending on the nature of the system being analyzed and purpose of the analysis.

A concurrent science, engineering, and technology (ConSEnT) guiding concept implemented in a cyber-based platform may be used to facilitate the implementation of SIA (Ting et al. 2003; Liao 2011).

2.6.1 ConSEnT for CEA Decision Support

The core analytical activity in a ConSEnT cyber environment is to support decisions on the actions in physical space by carrying out analysis in the information space, i.e., the concept of cyber-physical systems (Chen et al. 2015). The processes contained in the centered circle in Fig. 2.6 depict the transformation of a system in physical space to its representation in information space, as well as the implementation of actions decided in the system's information space back to its physical space. The 14-step procedure described above may be used to facilitate these processes. There are at least four additional factors to be considered in a concurrent fashion in this analysis:

Systems requirements – What are the required functionality and desirable design considerations of the CEA system under study? How critical is each requirement or consideration?

Mission scenarios – What are the site-specific conditions that would influence the design and operation of the CEA system?

Candidate technologies – What are the available technologies or resources that could be implemented or utilized to satisfy the systems requirements? What is the technology readiness level of each technology?

Systems configuration and design – How would the necessary hardware, software, and other components be integrated into a functional system?

Figure 2.7 shows the computational and functional components of ConSEnT. It also emphasizes the importance of modularity, interrelationships, and concurrency of the components. The starting point of analysis is the system scope and objectives. The outcome of analysis is to support decisions and provide actionable analytics at the strategic, tactical, and operational levels. The computational resources needed are (1) informatics for managing the capture and flow of data, information, knowledge, and wisdom; (2) modeling and analysis tools for processing and interpreting

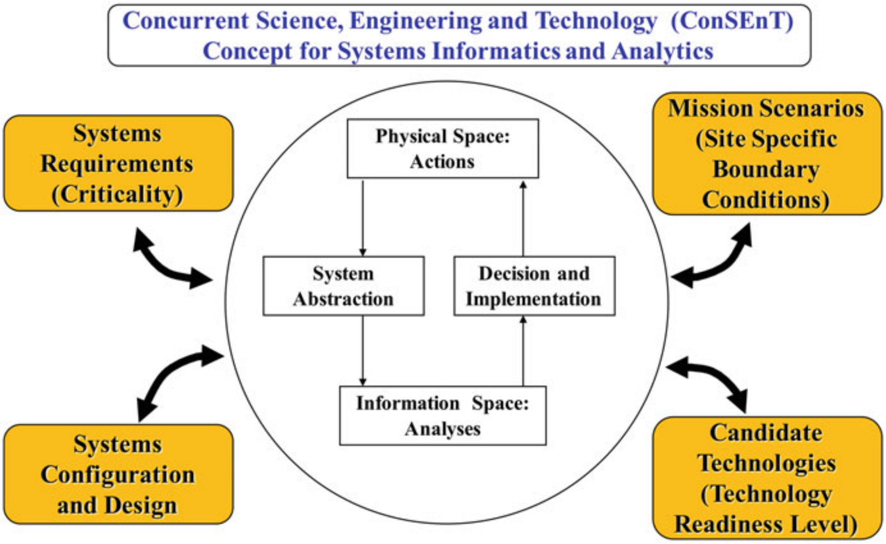

Fig. 2.6 ConSEnT concept for systems informatics and analytics

the information; and (3) decision support to connect the outcome of analysis to actions. The purpose of the ConSEnT cyber environment is to make all the resources available to the users in a way that facilitates broad and near real-time participation.

2.6.2 Decision Support and Analytics

Analytics is a way to discover and communicate key and meaningful characteristics in information. It has become an effective way of evaluating the performance of systems. It can be used to support decisions in various fashions. All available and emerging data processing and visualization tools have been used to produce and present analytics; many are custom designed for target audiences. For CEA systems, useful analytics are as follows:

- Technical workability
- Maintainability
- Controllability
- Reliability
- Productivity
- Economic competitiveness
- Energy efficiency
- Resource requirement
- Environmental impact

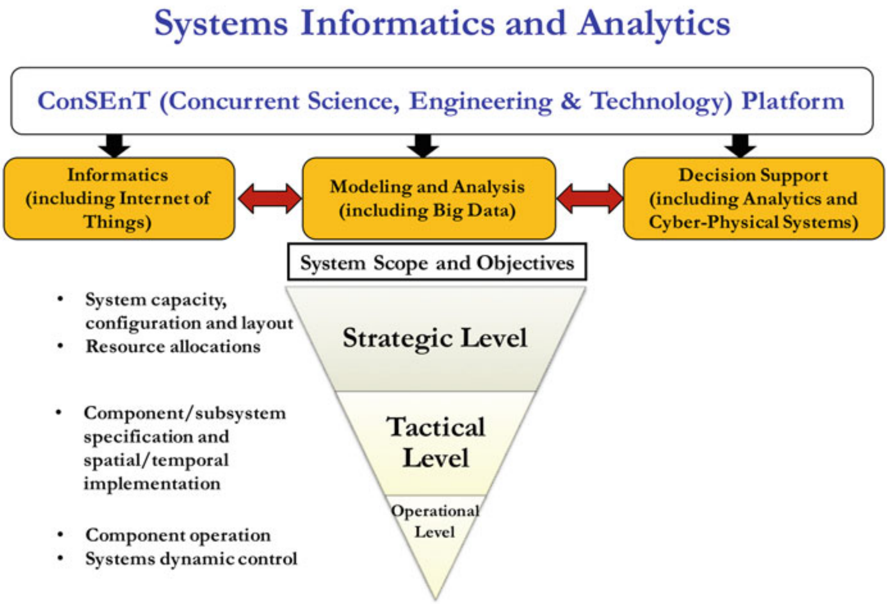

Fig. 2.7 Computational and functional components of ConSEnT

- Ecological harmony
- Social acceptance
- Optimization ability
- Operation and management capability
- Sustainability

Some of the above analytics may need to be expressed by a number of sub-analytics. For example, economic competitiveness may include capital investment, operating cost, revenue, return on investment, etc. Productivity may be expressed by sellable harvest per unit production area or revenue per unit input.

2.7 Current and Future CEA Challenges and Opportunities

The concept and practice of CEA are not new. However, there have been continued development, and the possibilities are plentiful. Just like other economic sectors, CEA, especially as part of urban food systems, has some unique challenges and opportunities. Some of the challenges and opportunities related to automation and systems informatics and analytics are discussed in this section.

2.7.1 *Challenges*

Automation

- Make return on investment attractive.
- Achieve systems optimization by proper integration of automation, plant culture, and controlled environment.
- Balance fixed automation and flexible automation (i.e., identifying appropriate level of necessary machine intelligence).
- Explore multiple uses of machines or parts of machines.
- Improve market demand and acceptance.
- Emphasize safety in operation.
- Enhance research and development capabilities.

Systems Informatics and Analytics

- Consider top level vs. process level.
- Make analytical tools expandable, compatible, adaptable, and transferable.
- Conduct effective system abstraction processes.
- Understand target participants and audiences.
- Validate systems models.
- Handle heuristic, uncertain, and incomplete information.
- Produce meaningful and useful deliverables from analysis outcomes.
- Coordinate multidisciplinary and multi-objective activities (e.g., ConSEnT).

2.7.2 *Opportunities*

Automation

- Take the advantage of improved technology readiness level and economic viability of automated information gathering/processing and materials handling.
- Build on past success of agricultural mechanization and modeling capabilities.
- Utilize effective communication systems and computational platforms.
- Enhance market acceptance.
- Increase the potential of spin-off technologies.
- Facilitate implementation of emerging technologies.

Systems Informatics and Analytics

- Establish information protocols and analysis algorithms for CEA.
- Develop a computerized environment for real-time information integration and analysis.
- Produce unified and robust models of CEA components and entire system.
- Perform studies at the system level to aid in design, operation, and research recommendations of CEA systems.

- Implement the systems informatics and analysis environment in a concurrent computational platform (e.g., ConSEnT), i.e., make things work better and together.

2.8 Concluding Remarks

It is probably an understatement to say that intelligent integration and optimized operation of urban CEA systems for achieving sustainability and competitiveness are a complicated task. Systematic approaches by involving multidisciplinary experts in evaluating and integrating available resources and candidate technologies will prove to be very productive endeavors. A concurrent science, engineering, and technology (ConSEnT) cyber environment may be created to enable real-time analysis, integration, design, management, and operation of urban CEA systems.

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