Article

A Study of the Business Model Development of Human Centric Lighting: Based on Eco-Science Methodology

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Abstract: Human centric lighting (HLC) is a promising market for innovations in the lighting market, but there is a lack of research on sustainable business models. Therefore, this study proposes a service, ecosystem, business model, and platform to innovate the HLC industry using eco-science methodologies suitable for manufacturing servitization. The study's findings show that the introduction of a platform-based B2B smart space service can have an impact on the spread of HCL. Accordingly, this study derives a business model and billing strategy that industry stakeholders involved in the smart space can cooperate with. Further, the study proposes a platform design to realize the proposed business model and verifies a service prototype to analyze the completeness of the research results and their economic ripple effects. As for the implications, this study presents an integrated perspective business model to revitalize the HCL market based on a systematic methodology from the convergence studies perspective. Additionally, there are academic implications that, instead of just proposing the research results, objectively evaluate and verify the completeness of the results. The results of this study suggest a future-oriented direction for the field of HCL.

Keywords: human centric lighting; eco-science; manufacturing servitization; service innovation

1. Introduction

Lighting has been developing for a long time as an essential element of our contemporary lifestyle. As technology advanced, lighting products have evolved from incandescent and fluorescent lamps to light-emitting diodes (LED) with high energy efficiency [1]. However, with the mass production of low-priced LEDs in China and Southeast Asia, it has become difficult to create added value only by manufacturing LEDs [2]. Accordingly, the servitization of the manufacturing industry is taking place [3,4].

Developed countries are establishing new business model strategies for the sustainable lighting industry, taking into account factors such as the difficulty of improving the trade balance and competition with low-priced products from developing countries. For example, IT companies such as Apple, Facebook, and Oculus acquired micro-LED specialized companies [5] and are now planning to develop an integrated lighting service model by adding the core technologies of the fourth industrial revolution, such as the Internet of Things (IoT), big data, artificial intelligence, and cloud technologies to the existing LED.

The LED lighting system based on the technologies of the fourth industrial revolution is known as human centric lighting (HCL) as it maximizes energy efficiency and human convenience through lighting control [6,7]. HLC is the most advanced lighting system that optimizes biological functions by automatically adjusting the illuminance, color temperature, and color of lighting according to the user's biological rhythm and surrounding environment. HCL has medical benefits as it affects the human body visually and non-visually and improves emotional stability and cognitive ability [8]. Furthermore, HCL is regarded as a potential alternative solution to solve social issues such as energy and environmental problems [9].

Therefore, studies in this field have focused on the medical effects of HCL [8,10,11], ergonomic designs (Deli et al., 2018; Nicolantonio et al., 2020), and lifelog-based platforms for smart lighting [12,13]. Although detailed research is essential for the advancement of the HCL field, macroscopic research from the perspective of convergence studies is also necessary for the spread and revitalization of the HCL industry. Yet, there is a lack of studies about business models, as governments and companies around the globe have been focusing on the technology development of HCL [7,14,15]. As market values are created and promoted through business models, research from an integrated perspective is necessary to develop a new HCL market.

This study aims to delve into a service model for revitalizing the HCL market using the eco-science methodology. It is a business model development methodology for the convergence industry, optimized for manufacturing servitization [16]. This scientific methodology helps develop a new service model for the convergence industry by simultaneously studying services, ecosystems, strategies, and platforms, which are essential elements for manufacturing servitization. The results of this study are expected to contribute to the growth of the HCL industry.

2. Theoretical Background

2.1. Human Centric Lighting

HCL is the most advanced lighting system that optimizes biological functions by automatically adjusting the illuminance and color temperature according to the surrounding environment [17]. HCL is similar to smart lighting in that it can save energy because it controls the amount of light based on a control system. However, while smart lighting focuses more on the aspect of energy-saving and convenience, HCL is a more advanced lighting system that takes into account the physical and mental states of consumers. This is because HCL also affects a person's sense of stability, sleep quality, work and learning efficiency, and health by considering not only the visual but also the non-visual effects of light [7]. Accordingly, various studies related to HCL have been conducted to date.

Figueiro [18] explains that many diseases, from sleep disorders to cancer, are caused by light-induced circadian system disorders. According to the paper, the HCL living lab experiment conducted on three groups (Alzheimer's patients, adolescents, and shift workers) showed that HCL was effective in improving depression and sleep disorders. In addition, studies by Cupkova et al. [10], Figueiro et al. [11], and Figueiro & Leggett [8] objectively demonstrated the life-improving impact of HCL. These studies have important implications in that they emphasize the necessity and impact of introducing HCL but are limited by a lack of management strategies for the industrial dissemination of HCL.

Deli et al. [19] and Nicolantonio et al. [20] conducted studies on HCL ergonomic design for the elderly, aged 65 and above. They undertook interviews with the sample group to propose an ergonomic lighting design that is elder-friendly and convenient; they carried out experiments after installing the lighting in nursing homes and hospitals. Such an ergonomic design has academic and practical significance because the importance of design is being emphasized in recent years, whereas the function of lighting was more important in the past. Nevertheless, as the paradigm of the lighting industry shifts from manufacturing to service [7], there is a limitation in the scope of product function or design research.

Cho et al. [12] and Vetter et al. [13] designed and built a lifelog-based HCL lighting control platform to provide an optimized HCL environment to users. The results of this study were meaningfully designed to give recommendations for an optimized system by comprehensively analyzing the user's emotional, activity, and environmental information (not just about location and lighting conditions). This platform is a key factor in revitalizing the convergence industry because it induces the participation of industry stakeholders and accumulates consumer databases [21]. Therefore, research on lighting control platforms has both academic and practical implications. However, it is important to acknowledge

that platforms are only developed when services are formed in the market. This requires a prior study on a sustainable service model.

To sum up the literature review, most research in the HCL field focuses on certain domains such as medical effect, design, and platform. While these are essential for the advancement of the HCL industry, to expand the use of HCL and revitalize the industry, research from a macroscopic perspective is needed, including services, platforms, and business strategies in an integrated manner. Therefore, in this study, a service model is developed based on the eco-science methodology for the sustainability of HCL and then verified empirically.

2.2. Eco-Science Methodology

Since the late 20th century, the manufacturing industry has faced challenges because of oversupply and weakened price competitiveness. While a product itself was a core resource in the era of manufacturing, the entire process of exchanging resources must be servitized to deliver new values to customers [22,23]. Accordingly, the paradigm of servitization of manufacturing has emerged for the innovation and sustainable development of the traditional manufacturing industry [3]. The servitization of manufacturing is not just about converging products and services but providing high-level services by collaborating with various industry stakeholders based on a platform [4].

However, it is very difficult to servitize a conventional manufacturing business. There are several reasons for this: first, as servitization in manufacturing has a cooperative ecosystem structure, there is a wide range of industries that must be considered for service innovation [24]. Second, prior research related to servitization in manufacturing has been limited to concept definitions or case studies. Therefore, there are insufficient studies that specifically suggest how to promote servitization in industry manufacturing [3,25]. Third, business model innovation methodologies, such as design thinking and PSS, deal with product innovation; and as such, their scope is narrow and applied to the convergence industry [26].

For this reason, many researchers have made efforts to develop innovative methodologies for convergence industry to enable servitization in manufacturing, and one of the major methodologies is the eco-science methodology. This methodology is a framework from a macroscopic perspective that derives business ecosystem strategies to plan for convergence industries and innovative services [16]. To plan for convergence industries and create service innovations, services must be designed in terms of deriving shared values, with the process consisting of ecosystem (E), platform (P), service (S), and strategy (S). This methodology develops a new business model by integrating ICT technology and industry stakeholders while comprehensively taking these four factors into account [27].

The core activities of the eco-science methodology can be divided into creating, sharing, and connecting. The first step is going through the process of creating the value desired by the customers of an industry or a company. This process derives services that include customer values. The next step is sharing values among stakeholders to create added value for a new industry. The added values are identified through a specific ecosystem analysis. Finally, in order to share values among stakeholders, a space is needed. This connecting of values can be done through a platform.

This methodology consists of phase, activity, and task. The phase is composed of the order of service derivation (S), convergence ecosystem definition (E), business model strategy (S), platform establishment (P), and service implementation (S), based on core elements. There are four to five activities under each phase, which are the performance units of each project. Finally, under the activities, different management tasks are included, and these are the smallest units for project execution and management. As a result, the eco-science methodology has a total of five phases, eighteen activities, and thirty-seven tasks. The framework of the eco-science methodology is shown in Figure 1.
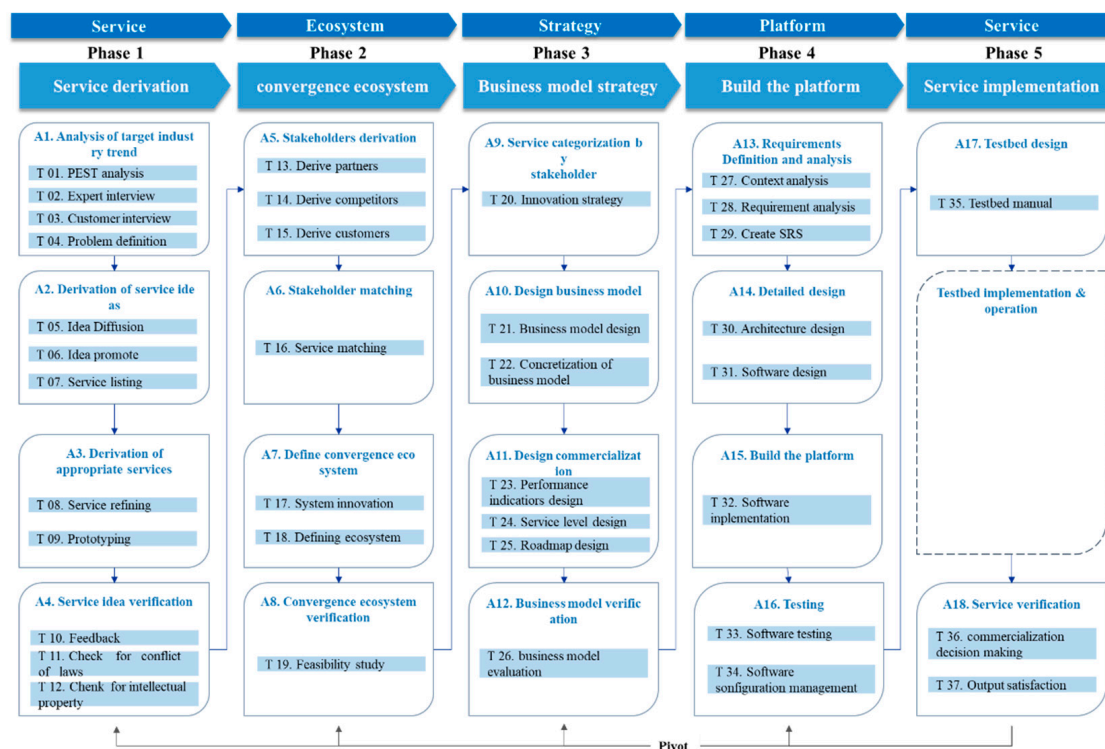
Phase 1 — Service — Service derivation

- A1. Analysis of target industry trend
  - T 01. PEST analysis
  - T 02. Expert interview
  - T 03. Customer interview
  - T 04. Problem definition
- A2. Derivation of service ideas
  - T 05. Idea Diffusion
  - T 06. Idea promote
  - T 07. Service listing
- A3. Derivation of appropriate services
  - T 08. Service refining
  - T 09. Prototyping
- A4. Service idea verification
  - T 10. Feedback
  - T 11. Check for conflict of laws
  - T 12. Chenk for intellectual property

Phase 2 — Ecosystem — convergence ecosystem

- A5. Stakeholders derivation
  - T 13. Derive partners
  - T 14. Derive competitors
  - T 15. Derive customers
- A6. Stakeholder matching
  - T 16. Service matching
- A7. Define convergence eco system
  - T 17. System innovation
  - T 18. Defining ecosystem
- A8. Convergence ecosystem verification
  - T 19. Feasibility study

Phase 3 — Strategy — Business model strategy

- A9. Service categorization by stakeholder
  - T 20. Innovation strategy
- A10. Design business model
  - T 21. Business model design
  - T 22. Concretization of business model
- A11. Design commercialization
  - T 23. Performance indications design
  - T 24. Service level design
  - T 25. Roadmap design
- A12. Business model verification
  - T 26. business model evaluation

Phase 4 — Platform — Build the platform

- A13. Requirements Definition and analysis
  - T 27. Context analysis
  - T 28. Requirement analysis
  - T 29. Create SRS
- A14. Detailed design
  - T 30. Architecture design
  - T 31. Software design
- A15. Build the platform
  - T 32. Software implementation
- A16. Testing
  - T 33. Software testing
  - T 34. Software sonfiguration management

Phase 5 — Service — Service implementation

- A17. Testbed design
  - T 35. Testbed manual
- Testbed implementation & operation
- A18. Service verification
  - T 36. commercialization decision making
  - T 37. Output satisfaction

Pivot

Figure 1. Eco-science Methodology Framework.

The eco-science methodology has a macroscopic view suitable for the business model design of the convergence industry and includes specific phases and tasks [26]; hence, it is useful to utilize in research. Further, the methodology is being actively applied in fields such as energy [26,28] and 3D printing [29]. Therefore, in this study, we propose a sustainable HCL service model based on the eco-science methodology to contribute to the HCL industry.

3. Developing an HCL Business Model

The purpose of this study was to propose and verify a business model that can contribute to the HCL industry. The eco-science methodology can propose a direction for innovation of the convergence industry from an integrated perspective through the process of establishing services, ecosystems, platforms, and strategies. Therefore, this study intends to propose a direction for the HCL industry by applying the eco-science methodology.

3.1. Phase 1: What Is the Right Service for the HCL Industry?

The purpose of this phase is to propose an appropriate HCL service through four sub-phases: analyzing the current status of the target industry, deriving service ideas, deriving appropriate services, and verifying service ideas.

The research team conducted an analysis of the current status of the target industry (Activity 1) to find an appropriate HCL service. For this analysis, a 1:1 in-depth interview of 10 lighting experts and a group interview of 20 consumers (Focused group interview, same as below FGI) was undertaken. As a result of expert interviews, the team was able to confirm that the IoT-based smart lighting market that uses LED is expanding, and interest in biorhythmic lighting is increasing. As a result of consumer FGIs, it was found that there was a demand for HCL, but the inconvenience of high installation cost, sensor malfunction, and divided roles of lighting companies were obstacles to the users of HCL.

Based on the interview results, we went through a process of deriving a service idea (Activity 2) that can maximize the value of customers while promoting the lighting market. Using service design tools such as the mind map, Six Thinking Hats, and Samper Map,

four candidate services were derived: smart space, healthcare, social-based lighting, and smart farm lighting services.

Subsequently, to fine-tune these candidate services, an importance-performance analysis (IPA) was conducted with the same experts and consumers, and the process of deriving appropriate services (Activity 3) was carried out. An IPA analysis is a priority evaluation technique that judges the importance and urgency of attributes [30]. As a result of the analysis, the smart space service, which belongs to the first quadrant shown in Figure 2 was identified as an appropriate service that should be implemented first. According to a survey by Beyer et al. [31], adults spend an average of 90% of their time indoors. Therefore, indoor lighting has a great impact on individuals and society at large. While HCL in specialized fields such as healthcare, education, and public facilities is important, for the advancement of the HCL industry, a model that allows frequent access to HCL in everyday spaces is needed to lower the barrier to entry for consumers.
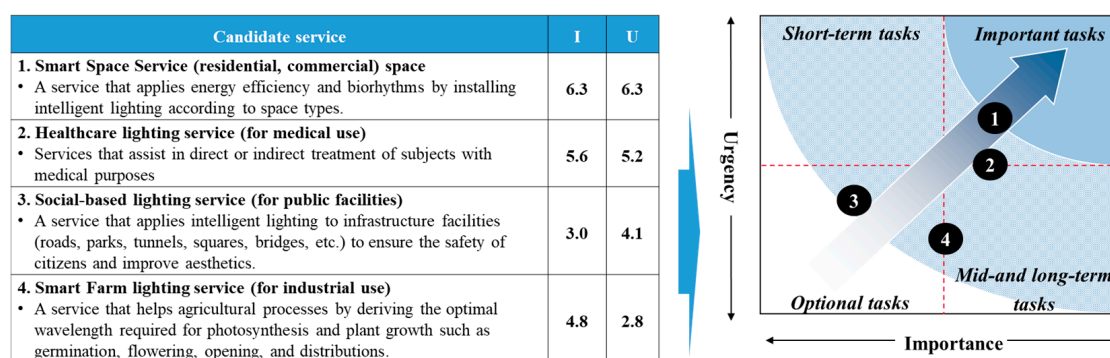
Candidate service	I	U
1. Smart Space Service (residential, commercial) space • A service that applies energy efficiency and biorhythms by installing intelligent lighting according to space types.	6.3	6.3
2. Healthcare lighting service (for medical use) • Services that assist in direct or indirect treatment of subjects with medical purposes	5.6	5.2
3. Social-based lighting service (for public facilities) • A service that applies intelligent lighting to infrastructure facilities (roads, parks, tunnels, squares, bridges, etc.) to ensure the safety of citizens and improve aesthetics.	3.0	4.1
4. Smart Farm lighting service (for industrial use) • A service that helps agricultural processes by deriving the optimal wavelength required for photosynthesis and plant growth such as germination, flowering, opening, and distributions.	4.8	2.8

Figure 2. IPA analysis results of HCL candidate services.

Thus, in this study, appropriate services were specified through the prototyping process. According to the previous customer interviews, customers felt inconvenienced in using HCL because of segmented service areas such as lighting purchase, control system installation, and post-management provided by different companies. In this regard, this study designed a non-stop HCL service. The service flow was divided into Step 1 (before service), Step 2 (in service), and Step 3 (after service), and major services and detailed activities were designed. Specific services, detailed activities, and service prototypes are shown in Table 1. Moreover, service idea verification (Activity 4) was carried out with the help of 10 experts who participated in the IPA analysis earlier, and it was confirmed that there were no issues with the prototype. The content of a smart space service is shown in Table 1 and Figure 3.

Table 1. Content of Smart Space Service.

| Service Flow	Main Service	Detailed Activity
	Lighting design	User-customized design, cost-benefit analysis
STEP 1	Space design	Product selection, interior design, and installation visualization
	Construction and supervision	Field construction, supervision
	Energy management	Remote control, time scheduling, and power cut off
STEP 2	Biorhythm management	Brightness control, color temperature control
	Data report	Energy usage notification, eco-mileage, and safety notification
STEP 3	Inspection	Remote inspection, visit inspection
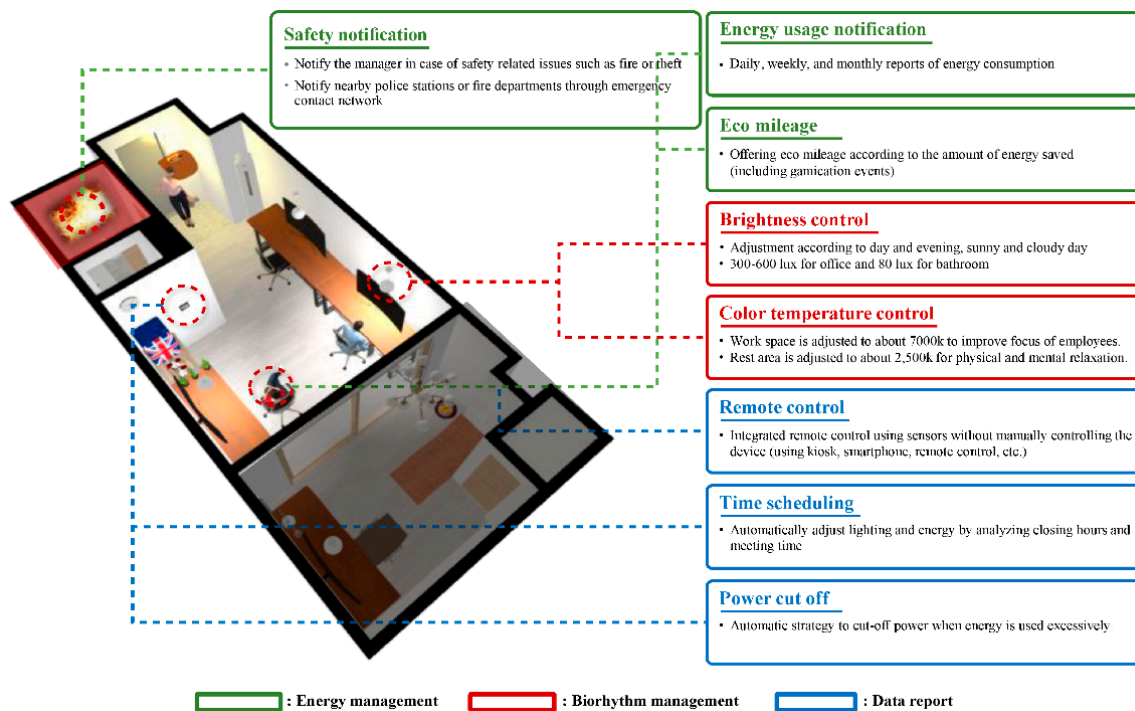
Figure 3. Visualization of Smart Space Service STEP 2 (Example: office).

3.2. Phase 2: How Will the Future Ecosystem of the HCL Industry Be Structured?

The HCL industry is a new market that has added the value of service to the traditional lighting industry. Therefore, it is necessary to analyze the current and future lighting ecosystem by utilizing the service value network (hereinafter referred to as SVN) to improve industrial value through cooperation with new stakeholders. SVN is a business ecosystem model that emerged to complement the limitations of Poter's [32] value chain theory [33]. Convergence ecosystem analysis is used in many business ecosystem studies because it considers different stakeholders, predicts the relationship between stakeholders, and offers comprehensive implications.

The subject of SVN consists of consumer, service supplier, Tier 1, Tier 2, and auxiliary enabler. In this study, based on this classification, the team performed stakeholder identification (Activity 5) and stakeholder matching (Activity 6) for the HCL industry. AS-IS stakeholders were identified through literature review, and TO-BE stakeholders were added in the case that the previously designed service is introduced. Further, interviews were conducted with 10 experts to diagram the lighting industry ecosystem. The roles and examples of HCL lighting ecosystem nodes are shown in Table 2.

The process of defining the convergence ecosystem (Activity 7) in the present and future was performed by applying SVN based on the stakeholders of the ecosystem. Figure 4 is the current lighting industry ecosystem (AS-IS). Tier 2 consists of a component manufacturer (hardware) and a lighting designer (software). Manufacturers belonging to Tier 1 mass-produce lighting designed by Tier 2 in factories. As Tier 1 and Tier 2 are supporters, there is no contact with consumers.

Selling lighting to consumers is done by wholesale and retail lighting distributors. Currently, lighting distributors do not cooperate with each other and operate in a competitive manner. Therefore, consumers have to visit each offline store in person. Additionally, after purchasing a product, installation and construction are carried out by other companies, drastically increasing the inconvenience for consumers.

Table 2. HCL Eco-system Stakeholders.

| Category	Role	AS-IS	TO-BE
Tier 2	Providing original parts and services to Tier 1	Lighting manufacturer	Lighting manufacturer Sensor manufacturer *
Tier 1	Providing products and services to service providers	Lighting parts company Lighting designer	Lighting parts company Lighting designer
Service Provider	Produce services through interaction with supporters and provide products and services through direct contact with consumers	Lighting distributor Installation/contractor	Lighting Solution Platform * Interior design companies * Lighting distributor Installation/contractor
Consumer	Consume products and services produced by service providers and help to improve the quality of products and services through feedback	Individual (small) Industrial (large scale)	Space 1 consumer * Space 2 consumers * Space 3 consumers *
Auxiliary	An institution that is not limited to a specific industry but is the foundation of society	Government agency	Government agency
TO-BE Direction of development	(In terms of convenience) Lighting purchase and installation/construction are not individually performed, but integrated services are provided through a lighting solution platform. (In terms of data) Smart space service is provided based on data on consumers and space by using integrated sensors. (In terms of design) Interior services tailored to the concept of smart space by space type.		

*: Nodes modified from TO-BE.
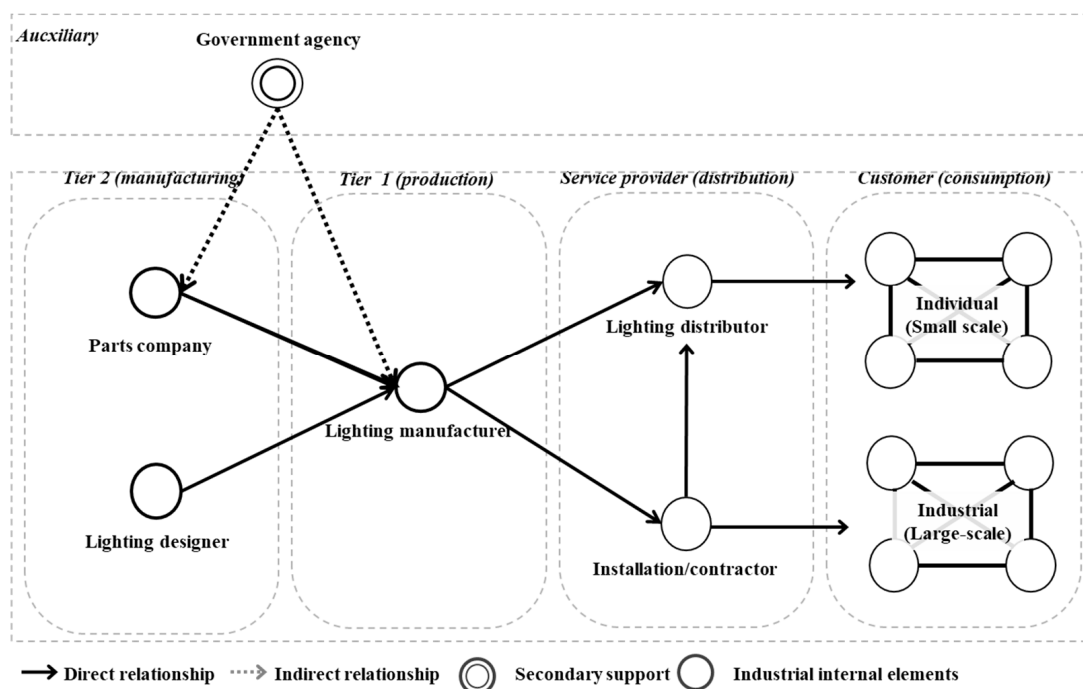
Figure 4. HCL AS-IS Ecosystem.

Consumers are divided into personal use, who consume a small quantity, and industrial use, who purchase a large quantity. Finally, government agencies, which are auxiliary nodes, have actively supported Tier 1 and Tier 2 that produce products for the revival of the manufacturing industry from a traditional point of view.

The business ecosystem (TO-BE) after the introduction of the HCL service mentioned above is shown in Figure 5. The nodes of Tier 2 are the same, but sensor manufacturers

have been added to Tier 1. Consumers have used lighting manually for a long time, but in an HCL service that improves convenience and efficiency, it is necessary to attach an integrated sensor to automatically control lighting and collect consumer data.
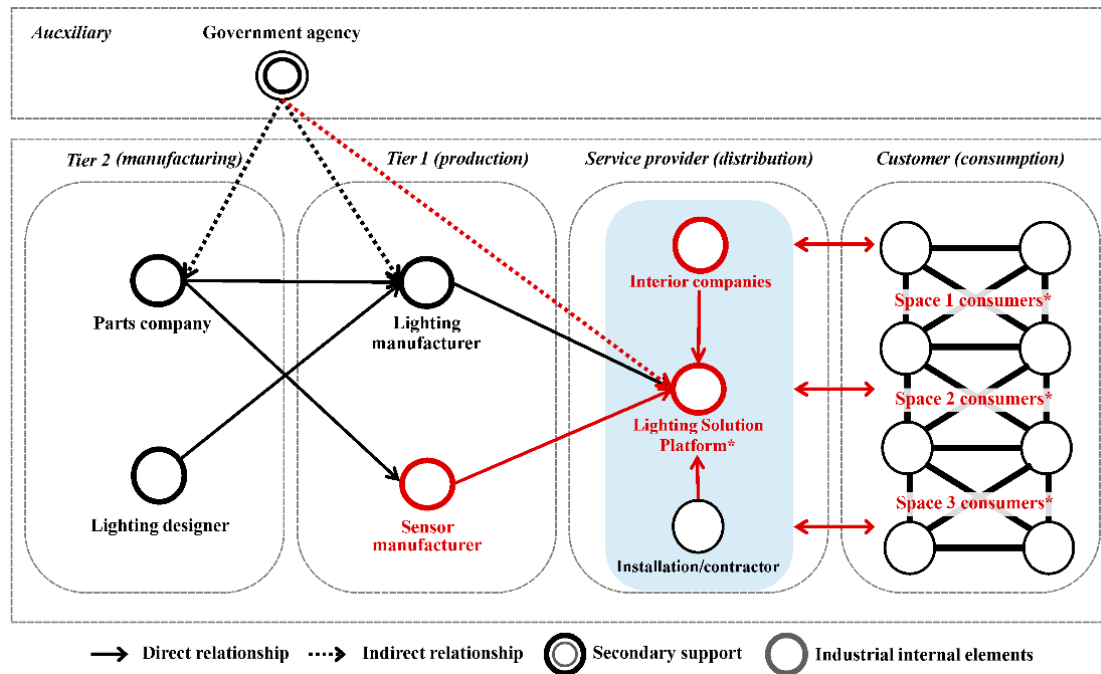

Figure 5. HCL TO-BE Ecosystem.

The biggest difference spotted in the TO-BE ecosystem is service providers and consumers. Lighting distributors that were dispersed individually will form a cooperative ecosystem on the lighting solution platform. Interior design and installation/construction companies that did not directly participate in the lighting ecosystem can collaborate to provide a non-stop service to consumers.

Unlike the AS-IS ecosystem, which classifies consumers according to consumption scale, the TO-BE ecosystem categorizes them according to the characteristics of a space. Today, lighting and space are inseparable, and the consumption pattern of lighting varies according to the characteristics of the space (residential use, office use, cultural enjoyment, etc.). In addition, it is predicted that customer relationships will become interactive thanks to customer feedback and data collection on the platform. Therefore, in this study, we tried to develop a business model strategy focusing on the lighting solution platform.

3.3. Phase 3: What Is the Business Model Strategy for the HCL Industry?

The HCL business model derived in this study is a platform-based integrated management solution that can collect and analyze consumer data. This is because the result of the ecosystem analysis of Phase 2 showed that the subject of innovation in the TO-BE ecosystem is the lighting solution platform. Therefore, the results of Phase 1 and Phase 2 were reflected in Phase 3 for service categorization by stakeholders (Activity 9). A service prototype was added to the core activities, and the TO-BE ecosystem nodes were divided into partners and customers.

In the business model design (Activity 10) phase, the business model canvas (hereinafter referred to as BMC) was specified as a business model. BMC is a business administration tool that explains the process and principles by which a company generates revenue, dividing them into nine blocks [34,35]. The results are shown in Figure 6.

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer segments
• Lighting manufacturer • Sensor manufacturer • Interior companies • Lighting construction/management company • Supervision company	• Lighting directing management service - Lighting design - Space design - Construction/supervision • HCL service - Energy management - Data report - Biological rhythm management • Post management service - Remote inspection - Visit inspection • Brokerage service	• Improve the spatial environment and the quality of life of residents through human centric lighting. • Contribute to vitalization of the domestic lighting industry ecosystem and strengthening of global competitiveness. • Contribute to a solution for global climate change by reducing energy use in buildings.	• Membership	• Space 1 - Apartment • Space 2 - Office - Industry • Space 3 - Retail - Sports
	Key resources		**Channels**	
	• Comprehensive data management system • Data management personnel		• Offline channel • Online channel	

Cost structure	Revenue Streams
• Interior/construction/supervision cost • Data management • Service warranty cost • Business operation cost	• Product/service brokerage fee • Platform service fee (per month) • Profit from the provision of warranty service after the contract period ends.

Figure 6. HCL BMC.

Next, the billing system of BMC was devised for establishing a commercialization strategy (Activity 11). In this study, the billing system was designed based on energy service subscription plans (ESSPs). ESSPs are billing systems that charge consumers a fixed price for energy on a subscription basis. It should be noted that this study focused more on B2B consumers than B2C consumers. This is because it is more efficient to sell services to institutions than to individual consumers when the infrastructure installation cost is considered.

After securing customers through the lighting production management service, smart lighting infrastructure must be installed. As its installation cost is a big barrier to customer entry, the partner company and the customer each pay 50% of the cost depending on the service contract period. The basic contract period is 10 years, but it is appropriate to plan it in a way that the longer the contract period, the higher the percentage the contractor should bear.

After the infrastructure is installed, a fixed price is received from the consumer every month during the HCL service process. The price should be 10% lower than the average usage fee before installing the HCL service. By introducing an energy-efficient system, the actual usage fee will be less than the price paid, and the difference becomes the profit of the partner company.

After the contract period ends, the product can be purchased or returned at the discretion of the customer. If warranty service is needed, a service fee is charged for each case to gain profit. The visualized figure of the ESSPs billing system is shown in Figure 7.
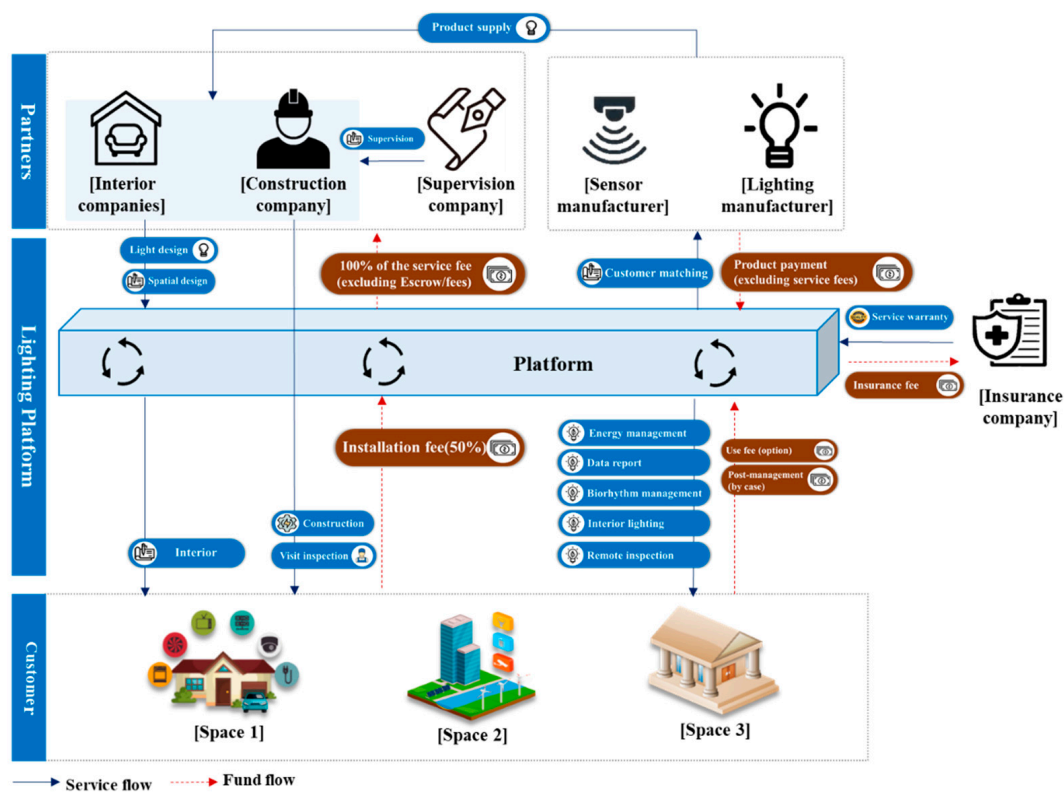
Figure 7. Billing Strategy for HCL BMC.

3.4. Phase 4: How Is a Platform for the HCL Business Model Built?

In the business ecosystem, a platform is an essential space of collaboration for different stakeholders, including users and suppliers, to expand and develop the overall ecosystem [16,36]. In this study, an application was designed and built to connect customers and partners of the HCL service.

The definition of requirements and the analysis (Activity 13) were conducted to identify the needs of consumers by reviewing consumer interviews conducted in the previous phase. In addition, architecture and detailed design (Activity 14, 15) was carried out in consideration of the consumer journey from start to end (Figure 8).

Based on the use case, we developed a living lab experimental application and proceeded with platform implementation (Activity 16). We automatized the development environment using Ansible, and the app was designed to enable large-scale deployment without being affected by the server using Docker-based packaging. The HCL platform developed through this study was designed to collect data such as the user's age, gender, number of family members, type of residence, and size of space.

The data is collected, stored, pre-processed, analyzed, and AI-based customized recommendations are offered. The interface was supported using Restful (HTTP) and Kafka (Broker) using Flume. Additionally, we developed a module that supports a preprocessing function for embedding data stored in the Hadoop distributed file system (HDFS) through Hive or Spark. The HCL Application UI is shown in Figure 9.
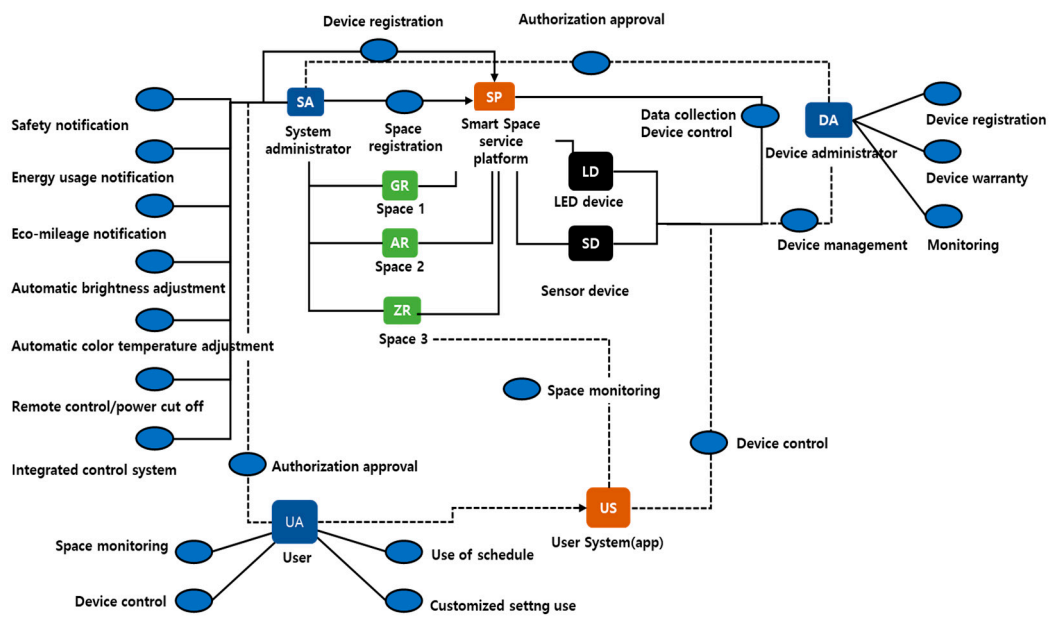
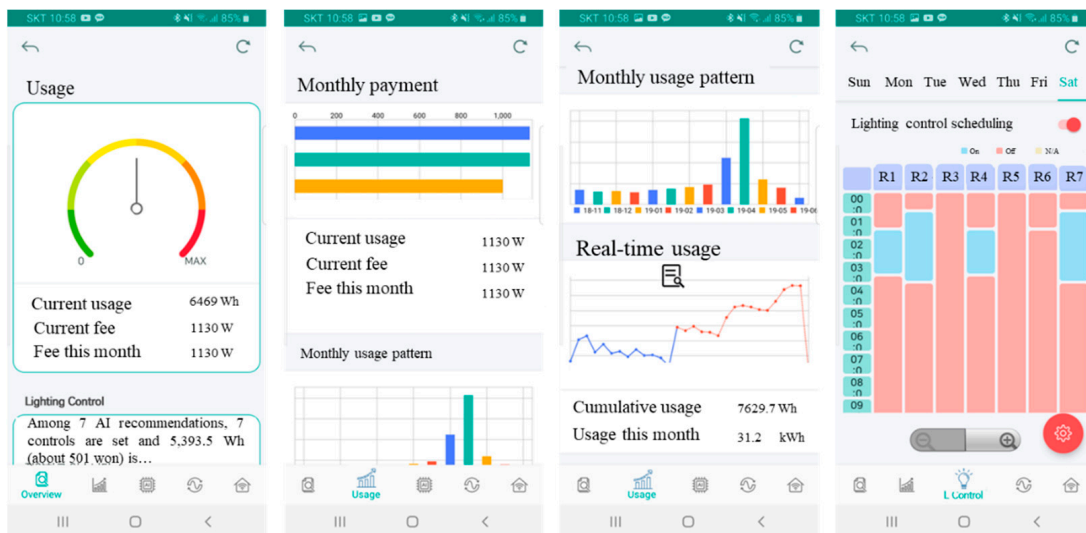**Figure 8.** HCL Platform Use Case.

Figure 9. HCL Application UI.

3.5. Phase 5: What Is the Industrial Impact of the HCL Business Model?

This study not only proposed an HCL service model based on the eco-science model but also tried to verify the research results objectively. Accordingly, a total of eight products from Company A and Company B, which have high market shares in the Korean lighting market, were installed in the office of the Korea Photonics Technology Institute to test the design, implementation, and operation (Activity 18, 19, 20) by connecting the products to the platform developed in Phase 4.

A substantiation service was conducted from May to November 2020, and the Bruce Merrifield-Ohe (BMO) assessment was conducted for service verification (Activity 21) for 10 light industry experts (from A to J in Table 3) who tested the space. The BMO assessment is a technique for quantitative assessment of the excellence of a new business model. In the BMO assessment, the attractiveness of the business model (average of 35 or more) is checked in Step 1. In Step 2, the suitability of the current market introduction (average of 35 points or more) is determined. The assessment table of the results is shown in Table 3.

The results showed an average of 88 points out of 120. This shows a degree of completeness of the business model from the substantiation service.

Table 3. BMO results.

Measurement Question		Points	A	B	C	D	E	F	G	H	I	J
[Step 1] Attractiveness	Market size	10	6	5	7	6	4	6	6	8	5	5
	Growth	10	9	8	7	8	9	9	7	8	9	7
	Competitiveness	10	8	6	6	7	7	9	6	9	9	8
	Risk diversification	10	7	8	9	7	7	9	7	8	8	6
	Industry rebuilding	10	9	8	9	9	6	7	7	7	7	5
	Social advantage	10	9	8	9	7	9	7	7	8	7	4
	Sub-total (A)	60	48	43	47	44	42	47	40	48	45	35
[Step 2] Compatibility	Financial power	10	6	5	5	3	4	5	6	5	6	6
	Marketing power	10	9	9	7	6	9	7	9	7	6	5
	Manufacturing power	10	9	9	8	9	8	8	9	9	9	9
	Technology power	10	9	9	9	9	8	7	8	7	8	9
	Raw material procurement power	10	9	8	8	9	8	8	8	8	7	7
	Management ability	10	9	7	5	7	8	5	9	7	5	4
	Sub-total (B)	60	51	47	42	43	45	40	49	43	41	40
Individual total (C = A + B)		120	99	90	89	87	87	87	89	91	86	75
Total (D = C/10)								88				

Finally, the influence and economic impact on the domestic and overseas lighting and related industries were analyzed in the case that the business model is introduced and increases productivity in the lighting and photonics industries. In this study, the computable general equilibrium was used, utilizing Ver. 1.0 of the Global Trade Analysis Project (GTAP), which can explain changes in macroeconomic variables such as gross domestic product (GDP), trade, and inflation, as well as interactions of activities by economic actors, such as producers, consumers, and governments around the world.

As there is a growing trend of developing countries exporting finished lighting products to developed countries, it is appropriate to include trade activities between countries in the analysis model [37]. Accordingly, it was judged that the analysis using the GTAP model was more appropriate than the industry-related analysis model, as the former can show the economic ripple effect in the domestic industry.

Two scenarios were designed based on the standard static model of the GTAP model. We attempted to find out whether sales in other industries would increase if the lighting industry grows to the level proposed in this study. In order to analyze the economic effect of a productivity increase due to technological change in the mining industry, two scenarios were used based on the standard static GTAP model. The scenario was set in which productivity increases due to technological development in the mining industry. In other words, there is a scenario in which sales increase relative to the same input amount due to technological development in the convergence of the mining industry, automobile, home appliance industry, medical care, environment, construction, agriculture and fishery, ICT, IoT platform, intelligent convergence module, 5G mobile communication, etc. In order to see the sensitivity under two different scenarios, an increase of 5% and 10% were assumed, respectively. GTAP DB used GTAP v.10 released in 2019.

The economic effects of technological development in the domestic mining industry are presented in Table 4. In the case of Scenario 1, the national welfare increased by 4213 million KRW, GDP increased by 0.29%, and the terms of trade representing the unit of imported goods obtained in exchange for one export product increased by 0.06%. The total exports of 11 industries increased by 0.24%, and imports also increased by 0.87%.

The overall domestic price index rose by 0.5%. Scenario 2 was found to have twice the economic effects of Scenario 1.

Table 4. The economic impact of HCL on South Korea by GTAP scenario.

Item	Scenario 1	Scenario 2
Sales increase assumption (Increase in sales assumed in the actual model)	5% (1.23%)	10% (2.46%)
National welfare (million dollars KRW)	4213	8426
GDP (%)	0.29	0.57
Terms of trade (%)	0.06	0.13
Change in total exports (%)	0.24	0.49
Change in total imports (%)	0.87	1.74
Price index (%)	0.5	1.0

4. Conclusions

The world is undergoing changes, such as the commercialization of 5G technology, the popularization of smartphones, the increase in electrical devices, and growing environmental issues [38]. HCL is a powerful alternative that fits this social paradigm to revitalize the energy industry while providing a solution to these social problems. Therefore, it is time to conduct an integrated study to spread HCL.

In this regard, this study is on the HCL business model, focusing on South Korea, where IoT infrastructure is well-established. Taking the eco-science methodology, the research team provided detailed clues of innovation for the lighting industry by deriving services in the HCL market (Service), defining a convergent ecosystem (Ecosystem), deriving a business model strategy (Strategy), designing a platform (Platform), and implementing the service.

Phase 1 confirmed that in order to revitalize the HCL industry, it is more effective to promote B2B smart space services that can be applied to all spaces rather than specific environments such as medical and public facilities. In addition, this phase also confirmed that the service should be developed in a way that can provide integrated non-stop service from design to construction and post-management of HCL.

To realize such a service model, it is necessary to link different stakeholders, technologies, and institutions. Therefore, in Phase 2, the AS-IS and TO-BE ecosystems were schematically illustrated. Sensor manufacturers, interior companies, and lighting solution platforms were added to the TO-BE ecosystem, and customers were segmented into space types. Moreover, it was understood that to expand the TO-BE ecosystem, many stakeholders must cooperate with each other based on the lighting solution platform.

In Phase 3, the business model was designed to match the appropriate services derived in Phase 1 with the stakeholders defined in Phase 2, focusing on the macro values such as improving the spatial environment, revitalizing the lighting industry, and solving climate change issues. Furthermore, an energy service subscription plan was proposed as a specific billing system.

Phase 4 went through the process of designing and building a platform that can operate the HCL business model. This platform is designed to collect data such as the user's age, gender, age, the number of family members, residential type, and the size of space. Such data is collected, stored, pre-processed, and analyzed to recommend customized lighting based on AI.

Finally, in Phase 5, lighting was installed in an office, and a testbed was built and operated in conjunction with the platform. Based on the results, business model assessment and economic valuation were performed by customers. Consequently, it was confirmed that the HCL business model derived in this study has a high degree of completeness and that the economic ripple effect is high when applied to the actual industry.

In this study, the HCL business model was developed as a way to innovate the lighting industry, and its feasibility was verified to enable commercialization. However, when manufacturing-servitization is promoted in the traditional manufacturing industry, the probability of conflict increases because it cooperates with new stakeholders and increases contact points with customers [39,40].

Therefore, research on risk management is necessary for stable commercialization. In a follow-up study, management risks are classified into technical risks [41], behavioral risks [42], and delivery risks [43], and how to solve each problem is addressed. The methods should be further studied; for example, risk aversion strategies to filter out customers who are not suitable for HCL services, risk transfer by contracting with insurance companies, and risk reduction strategies to reduce risks in advance by investing money in ICT sensors [4].

In addition, in the follow-up study, it is necessary to study the interaction between the stakeholders derived above in detail. Based on the SVN results of Phase 2, it is necessary to study the communication strategy for each link between nodes. In particular, innovation at the industrial level is important not only for internal stakeholders but also for the role of the government [16].

Therefore, it is necessary to study how the Korean government can support HCL services from a policy perspective. Finally, the most important success factor of a business project is the improvement of the business model according to customer feedback. In this study, to verify the commercialization feasibility of an HCL service, a survey was conducted with experts in the lighting industry, and the economic value was evaluated using GTAP. However, there is a limitation in that it was not possible to conduct a survey targeting consumers. Therefore, a follow-up study is needed to improve the service model based on customer feedback.

The implications of this paper are as follows: First, this study is convergent research that comprehensively examines the HCL services ecosystem, business model, strategy, and platform. In general, prior studies in the lighting industry have focused on one of the above keywords, but in this study, HCL is approached from the convergence perspective, providing macroscopic insights. Second, this study garnered objective reliability by verifying results through actual demonstrations rather than simply proposing a business model. It is meaningful in that it proposes the development direction for the HCL industry, which is at the early stage of market formation.

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