New research trends in artifactology

— Modeling of individuals and socialization technology —

Jun OTA[1]*, Nariaki NISHINO[1,2], Tatsunori HARA[1] and Toyohisa FUJITA[1,2]

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The aim of Research into Artifacts, Center for Engineering (RACE), the University of Tokyo, is to solve problems related to artifactology. The center has now entered its third stage. A new approach in the problem-solving process has been proposed in this paper. The scenario for problem solving starts by establishing a problem using the concept of co-creation. Next, models related to artifacts are constructed by integrating the methods used in experimental economics and techniques of experimental psychology into computational science, data analysis, and simulation technology. Modeling of individuals is realized by focusing on three processes: recognition of individuals, activities of individuals based on recognized results, and value construction of individuals. This proposal of RACE includes the socio-technical viewpoint of multi-stakeholders and the human-centered viewpoint of modeling of individuals. Several new research topics are presented, including a novel modeling methodology for product service systems (PSS).

Keywords : artifacts, modeling, individuals, social technology, co-creation

1 Introduction: The aims of artifactology

Research into Artifacts, Center for Engineering (RACE), the University of Tokyo, was established in 1992 to deal with the science of artifactology. The center was set up with the aim of engaging in education and research relating to artifactology. The term “artifactology” is discussed in the paper, “The Creation of New Paradigms for Engineering”[1] by Hiroyuki Yoshikawa, former president of the University of Tokyo. The paper states firstly that the many difficult problems we face in relation to the environment, wealth and poverty, safety, and health or, in other words, the “modern evils,” as the results of human behavior in pursuit of safety and wealth are utterly unpredictable. It also stresses that existing academic frameworks are formed depending on discipline boundaries and restricted viewpoints, and are a cause of these problems, to say nothing of difficulty in applying them to solve these problems. As a solution, it proposes the academic framework termed “artifactology” as a new academic discipline that studies all that humans create, denies separate sub-disciplines, and takes in all viewpoints. In other words, it is not a conventional deduction-based academic discipline, but a discipline based on abduction to derive hypotheses, laws, and behavior.

This paper first discusses artifactology in relation to its neighboring disciplinary areas, and then proposes new problems and directions as well as a research methodology for future artifactology, as put forward by RACE. It then outlines concrete problems relating to artifactology extracted by center members in line with the created new direction and methodology.

2 Relation between artifactology and other disciplinary areas, new problems in artifactology

2.1 Positioning of artifactology

This subchapter surveys the disciplinary areas related to artifactology. In his book, “The Sciences of the Artificial,”[2] Simon attempts to create an academic framework relating to artifacts made by humans, in contrast to the explanation given by the natural sciences. He argues for an academic curriculum that deals with artifacts, from the perspective of evaluating design, searching for alternative solutions, and extensions to design societies including bounded rationality. Ichikawa[3] defines science that does not assume backward causality as artificial science, and states that its outcomes are evaluated by humans on their beauty and usefulness. Gibbons *et al*. pursue the changes in knowledge production modes in modern society.[4] They term conventional knowledge produced by the internal mechanisms in each of the disciplines as mode 1 (to which general sciences correspond), and knowledge that is produced in transdisciplinary areas that are more open to society as mode 2. On the basis of their classification they consequently discuss the relation between modes 1 and 2. The “Comprehensive Synthetic Engineering” discipline is defined as “an engineering transdisciplinary research area not seen in traditional engineering that relates artifacts designed and manufactured by mobilizing all the engineering frameworks and knowledge.”[5] Because of the importance of this, the Science Council of Japan set up the Committee on Comprehensive Synthetic Engineering in

1. Research into Artifacts, Center for Engineering (RACE), the University of Tokyo 5-1-5 Kashiwanoha, Kashiwa 277-8568, Japan * E-mail: ota@race.u-tokyo.ac.jp, 2. School of Engineering, the University of Tokyo 7-3-1 Hongo, Bunkyo-ku 113-8656, Japan

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2005. Awareness of artifactology issues is therefore shared among many researchers, and it is clear that the importance of a subject-independent transdisciplinary framework continues to be recognized.

“Problem solving” is one of the aspects intimately related to artifactology within this subject-independent discipline. Smith[6] divides problem-solving in the wider sense of the word into two approaches, namely problem setting, which comprises problem identification, definition, and structuring, and problem solving in the narrow sense, which consists of diagnosis and alternative solution generation. In many cases, the latter approach obtains a suitable solution through appropriate modeling and optimization methods. Various methods have been proposed for the former approach,[7] but overall they are predominantly termed Soft System approaches.[8] A typical method is Soft Systems Methodology (SSM).[9] This method aims at multiple problem stakeholders agreeing with others, termed accommodations, and, although it proposes a model consisting of seven steps, there is much qualitative discussion. A merging of both approaches is essential to achieving comprehensive problem solving, and although several attempts have been undertaken (e.g., reference [10]), to date no firmly established methodology exists.

Against this background, we wish to take a high-level view of the positioning of artifactology in which RACE is involved. The external report formulated by Science Council of Japan’s “New Academic Framework Committee” in 2003, discusses design science, which is closely linked to artifactology, as follows:[11][12]

> Taken in a broad sense, the term “design science” is fitting for intellectual activities that are aimed at the “pursuit of things that should exist.” Design science must be a new science that addresses purpose and value head-on. As design is undertaken for the purpose of people, the subject of design science is artifactual systems. A new academic framework is built through a new concept of the “principle of order,” which is common to both the humanities and sciences. The three stages, the “world of materials,” the “world of biology,” and the “world of humans,” correspond to “physical science,” “life science,” and the “humanities/social sciences,” respectively. Subjects in design science are not limited to these respective domains, but it studies “artifactual systems” linked to any of the three aforementioned domains. Design is an exceedingly human activity that accomplishes its purpose by combining unchangeable laws and changeable programs and realizes value, and design science is an “artifactual system science” that provides it with a rational foundation.

In other words, artifactology is an academic framework for the new creation (design) of artifactual systems in a universal sense, and, in contrast to the aforementioned problem-solving, can be said to place emphasis on creating artifacts.

2.2 Disciplines artifactology research has entered and new problems

Let us now look at the kind of research RACE, which is involved in artifactology, has conducted. The center started Phase I (1992–March 2002) under a three-division system; namely, design science, manufacturing science, and intelligence science. Problem analysis, then generalization were performed for artifactology (setting off the research agenda), and the foundation was laid for a theoretical structure for the hypotheses and discoveries that realize new functions. Dematerialization and breaking of the limitations of specific disciplines were extracted as the mission of artifactology education and research. These activities also underlie the ideas involved in building a new academic field with more possibilities through a unified reconsideration of various existing fields from a perspective of functionality and universality. However, the main outcome in Phase I was the extraction of problems, and it cannot be said to have succeeded in building a methodology to tackle modern evils. Phase II (April 2002–March 2013) therefore began with the objective of applying the outcomes of Phase I to actual problems (study on creation processes). Four fields that needed to be studied in realizing this mission were proposed, and a division set up for each. First, digital value engineering was proposed as a problem and a knowledge representation method in artifactology. Next, the following were positioned as methodologies for dematerialization: life cycle engineering, which deals not with mass production or consumption but with recycling and maintenance; service engineering, which discusses artifacts from the perspective not of the manufacturing of material but of the provision of functionality; and co-creation engineering, which deals with consensus building among individuals and the construction of the associated society, and links the aforementioned life cycle engineering and service engineering from the perspective of transcending the limitations of specific disciplines.[13][14] Further, the Value Creation Initiative (Sumitomo Corporation) Division dealing with value, an important concept in artifactology, was in operation from December 2005 until March 2010. The Phase II outcomes were, in the life cycle engineering division, the establishment of an academic discipline that extended the existing life cycle engineering to cover monitoring and maintenance. In the service engineering division, a design theory for services not constrained to material functionality alone was obtained; in the digital value engineering division, new expressions of knowledge and the creation of value was obtained; and in the co-creation engineering division, a problem-solving methodology through co-creation of various acting subjects in various fields was obtained. The co-creation engineering division built the foundation for the integration of the other three research divisions. The Value Creation Initiative

Division dealt with human values, and performed their modeling.

Considering the overall outcomes of Phase II, it can be said to have generated many research outcomes for design science with its focus on the material world, e.g., design of artifacts that take resource constraints and waste into consideration, and technologies for a large-scale complex simulation base. However, the discussion from the perspective of how to ensure the permeation of created artifacts among “diverse, changing humans” and in “diverse, changing societies,” was still insufficient and issues still remained.

3 New direction in artifactology

3.1 Proposed new direction

Phase III (April 2013–onwards) is currently in progress at RACE. We considered it necessary, based on the outcomes and limitations of Phase II, to extend the subject of study in Phase III to include the humanities/social sciences, and to aim at building an academic framework for artifactual system science that is more comprehensive; specifically, extending the subject of study from the world of materials to include the world of biology and the world of humans. To this end, we reorganized and formed two divisions that deal intensively with the themes of artifacts, humans, and society from a perspective of strengthening the merger of the existing four divisions, and of promoting interaction between division members. Figure 1 shows the transition of the involvement of RACE in artifactology. It was discussed and created based on information in reference [15]. A structure was decided upon that consists of two divisions: from a more micro-perspective, the Human-Artifactology Division (division for the study of artifact-human interaction), which deals with the permeation of artifacts among diverse, changing humans and artifact-human interaction; and from a macro-perspective, the Socio-Artifactology Division (division for the study of artifactology within society), which deals with permeation of artifacts into diverse, changing societies and their interaction.

The division for the study of artifact-human interaction studies the relation between humans and artifacts while aiming to solve a variety of social problems. On the basis of value models obtained in Phase II and knowledge gained in service engineering research, it aims at an important issue relating to people, namely, modeling of individuals. That is, modeling of diverse individuals that also includes in its consideration the dynamics of values that change through the existence of artifacts. While dealing with concrete problems such as product service system design and man-machine cooperation systems, we will clarify how artifacts and humans are related from a universal perspective.

The division for the study of artifactology within society studies the relation between society and artifacts while aiming to solve a variety of social problems. On the basis of the concept of life cycle systems and the concept of co-creation obtained in Phase II, it aims at socialization technologies for artifact creation applied to society, and aims to propose a co-creation design methodology for artifactual systems, incorporating objective setting and solution searching for problems the objective of which is

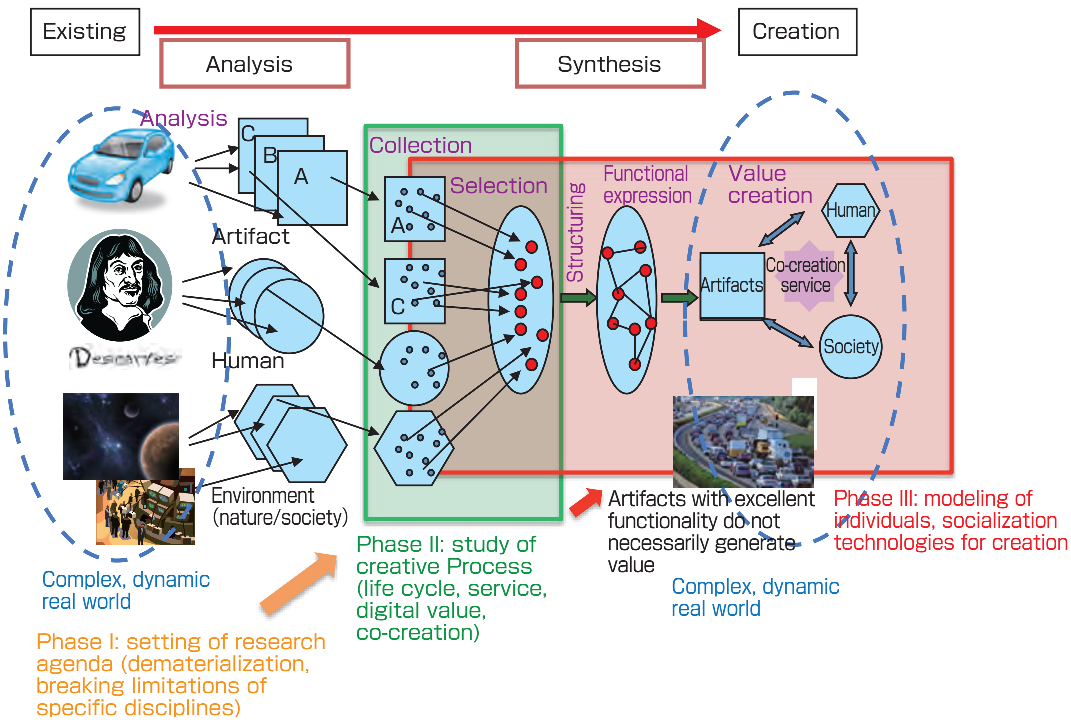

Fig. 1 Transition of the involvement of Research into Artifacts, Center for Engineering, the University of Tokyo, in artifactology.

unknown, through cooperation among stakeholders.[16] Here, social technology signifies “technology to build new social systems, integrating knowledge from multiple areas in the natural sciences and humanities/social sciences.”[17] While dealing with various problems—e.g., co-creation technology strategies dealing with optimum design in interdisciplinary areas and global environmental problems—affiliated with comprehensive synthetic engineering, in itself active in various academic fields, it will clarify shared structures related to humans and society. Through the cooperation between the aforementioned two divisions, the overall center target is set as “socialization technologies for the creation of artifacts based on the modeling of dynamically changing individuals,” and the aim is to continually construct continuous harmonious relationships between artifacts and individuals/society/environment.

3.2 Concrete research methodology

In the previous subchapter, we explained that we will use an approach from the perspective of modeling of individuals and socialization technologies for artifact creation. We now explain this methodology in concrete terms.

Let us first look at “modeling of individuals.” This problem was also dealt with in Phase II, but the main outcome was modeling of individual differences, and hardly any work was done on the changing state, i.e., dynamics, of individuals. In real-world problems, it is normal for actors to gradually change, and this problem is therefore extremely important. The discussion of problem-solving starts from the concept of hierarchical systems. Modeling is performed for humans and artifacts focusing on the complexity of the subject. Describing these as models results broadly in the models shown in Fig. 2. The models consist of elements such as body parts and parts that form humans and artifacts, which in turn combine to form groups, and ultimately society. The individual boxes can be thought of as being formed from two or more levels.

A great deal of modeling has been performed for the respective steps, but modeling that connects the different steps is in general extremely difficult. One reason for this is the fact that the forms of expression vary between models. There is furthermore the discussion that, when the model for one step is homogeneous, the neighboring step characteristically is heterogeneous.[18] Although various techniques have been proposed already for the modeling of hierarchical structures,[19] there is still room for improvement from the perspective of general knowledge. For simplicity, we will consider the individual in one box to be expressed in the lowest part, and will be modeled in the form of the interaction between the homogeneous elements (each having their internal state, and for this state different values are obtained) in the top part of the box directly below. In this case, the internal state of the elements and the differences in interaction form the diversity of the individuals, and its dynamics form the dynamics of the individual.

Much research has already been done on social technology (e.g., reference [20]), but we deal here with the term “socialization technology” from the problem-solving perspective. There exist various processes for this, but usually the modeling outlined in Fig. 2 is performed and the process progresses based on the derivative analysis, manufacturing, evaluation, and maintenance steps (Fig. 3(a)). Manufacturing in this context has the wider meaning of the introduction into real society of obtained solutions, and is not limited to the making of objects. Artifact creation is also a problem-solving process, and is based on similar processes. However, in this context, it is taken to consider aiming at “socialization technologies” from the preceding step, that is, the problem setting step (Fig. 3(b)). This corresponds to the aforementioned problem-solving in a broad sense, as put forward by Smith.

It is well known that, in the creating of artifacts, it is

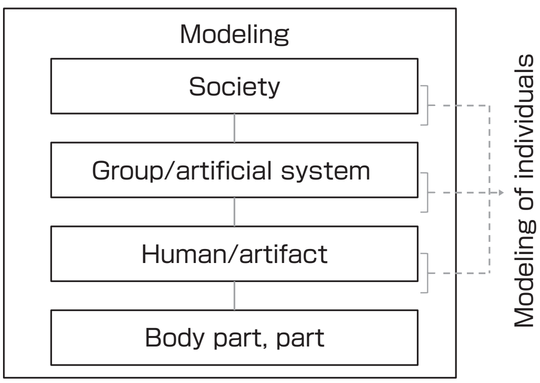

Fig. 2 Overall view of modeling and modeling of individuals

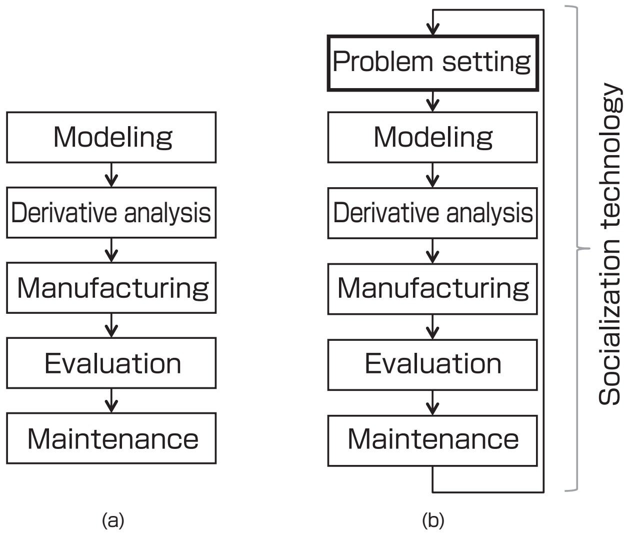

Fig. 3 Artifact design process involving socialization technology: (a) Design process focusing on problem solving in a narrow sense, (b) Design process involving socialization technology

necessary to assume an environment in which there are multiple interested parties whose interests do not necessarily coincide, that is, a multi-stakeholder environment, and the formalization as well as the systemization of the problems in this structure is considered useful in socialization technologies for artifact creation. This problem-solving is intimately linked to class III problems as put forward by Ueda *et al.* According to Ueda *et al.*, problems in the design of artifactual systems can broadly be divided into three classes.[21]-[23] Of these, class III problems are explained as "problems with incomplete specification, where not only the environment but also information relating to the objective cannot be predicted by the observer, and are not exhaustively described."[7] Reinterpreted based on this explanation and the discussion of the previous step, this means that this is problem-solving for problems with a vague objective and specification, where the designer and receiver cooperate to simultaneously determine the objective and specification. These problems are extremely burdensome to handle, and were not really tackled head-on in Phase II. Therefore, in Phase III, we aim to deal with these problems as well as the systemization of the problem-solving method, in solving a few real-world social problems.

We wish to outline a scenario for the solving of systems that include these problems.

(1) First, we use data analysis technology, simulations, and computational science as the foundation for our modeling. Many members of our center are specialists in these fields. Additionally, we are considering the inclusion of methods in experimental economics and experimental psychology, which experimentally derive, from an economic and psychological aspect, the behavioral principles and interaction of agents composed of a comparatively small number of acting subjects.

(2) Next, modeling of individuals is performed. The individual is treated as an agent, and modeling is performed from the following three processes: recognition of individuals, activities of individuals based on recognized results, and value construction of individuals, which forms the basis for generating these activities. The aforementioned interaction is expressed in each corresponding step, and facilitates the expressing of interaction and mediation between multi-stakeholders. Such models are linked to each step and aim at modeling society, humans, and artifacts.

(3) On the basis of the modeling formed in (2), problem-solving is performed.

Figure 4 gives an overarching view of this problem-solving scenario. Dynamically changing individuals are modeled using the techniques shown on the left hand side of the image. These contribute to the overall problem-solving process described on the right hand side, but are mainly made use of in the modeling phase.

This completes the discussion of the framework. Individual applications from various fields need to be applied and described from the perspective of the creation of an academic artifactology framework, and their universality needs to be discussed. We aim for the systemization of academic disciplines that transcend the limitations of specific disciplines, namely, socio technology for problem setting, function theory for modeling, synthesiology for derivative analysis, manufacturing theory for manufacturing, metrology for evaluation, and maintenance theory for maintenance. This is in line with the framework for the design engineering curriculum proposed by Yoshikawa.[24]

4 Research cases and remaining issues

In this section, we outline some concrete research cases and remaining issues.

4.1 Setting collaborative research topics through member collaboration: A product service system modeling scenario

A product service system is "not only for selling products, but also for meeting the needs of users through a combination of product and service." Using Service Explorer, the world's first service CAD tool developed by RACE, and by incorporating methodology based on experimental economics techniques, we built an interaction model for designers who design a service, service providers running the service, and service receivers who benefit from the service. We will first explain the general approach of the methodology based on experimental economics techniques, then outline its application to product service systems, and lastly explain the methodology that applies it to the themes concerned.

4.1.1 Application of experimental economics techniques to product service systems

In experimental economics, controlled socioeconomic systems are created in laboratory environments, such as that shown in Fig. 5, where the behavior of actual people

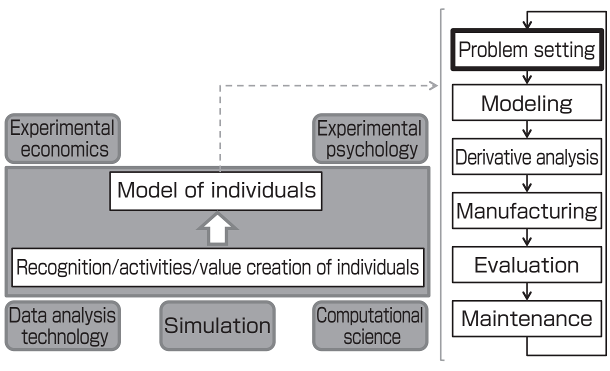

Fig. 4 Problem-solving scenario

as subjects is observed and analyzed. Specifically, based on the induced value theory,[25] this is characterized by the controlling of subject preferences through the giving of remuneration (mainly in local currency) for points obtained during the experiment. In other words, the experimenter induces specific utility functions in the subject, observes the behavior within a virtual social system where these utilities are controlled, and by looking at each actor's utility change and overall social surplus, it becomes possible to deal with this explicitly as value. This method enables the modeling of the process of "value construction of individuals" outlined in chapter 2. The techniques for experiments with subjects are the same as the framework for experimental economics thus far, but the novelty lies in developing this, based on the results obtained as actions by real humans, from the level of the individual acting subjects (agents) into a model of the value construction process. It is for this reason that it is necessary to consider in advance, and carefully plan, the framework to conduct an experiment, its behavior patterns, and interaction. Through the combination with the Service Explorer, this has now become possible for the first time. In the case of singular agents, action is based on rationality and is therefore easy to model, but in the case of multiagent systems, the problem of how each agent behaves is inherently difficult owing to the interdependence of all agents' values. A great deal of research has been done that discusses states of static equilibrium such as the Nash equilibrium, but if we include the complex dynamics surrounding this, it is difficult to maintain that we have a sufficient understanding of these particulars. We particularly lack good understanding from the perspective of the construction of value. Techniques centered on experimental economics can contribute to the modeling of this aspect.

Using the aforementioned kinds of methods enables us to verify in economics experiments how a designed product service system functions in a virtual society in a laboratory before applying it in the real world. If an economics experiment reveals that a product service system, however excellent its functionality, does not show sufficient value from the perspective of benefits for a business environment or for consumers, it is clear that it requires either a redesign of the product service system structure, or a change in the structure of a social system that generates high value; that is, a structural change in the system (mechanism). In this way it would become possible to develop a new artifact design theory.

Fig. 5 An actual economics laboratory

4.1.2 Modeling a product service system

Product service system design is not design of the primarily singular artifacts called products, but rather designing the creation of functionality by both products and services, as well as its method of delivery. This necessitates a comprehensive system design that also takes the interaction between humans and society into account. It is essential that there is a modeling of individuals that incorporates mechanisms of purchasing, usage, and participatory behaviors of receivers with bounded rationality, mechanisms that change due to the various interactions within society, e.g., with competitive products or other consumers. We believe that the successive creation and modification of product service systems based on this will be effective.

Figure 6 illustrates the concept of this collaborative research theme applied to the example of a smart house. A smart house is built around physical artifacts, such as a home, electrical appliances, and various pieces of equipment, and allows for the consideration of possibilities in the provision of various services that meet the consumer's needs, through usage expressed by energy supply and demand.

For this concept we first use the Service Explorer to model the receiver, centering on the artifacts, and design the functionality of the product service system (Fig. 6, bottom left).

Next, we refine the model of individuals on aspects of recognition, behavior, and value, using the technique of observation of the receiver's decision-making in the economics experiment outlined in the previous chapter, and modify and refine the product service system (Fig. 6, top left). This means that we perform both function design and design of systems (mechanisms), which takes the interaction of humans and society into account, in the laboratory. We then analyze the systems in more detail using the data obtained through actual service provision as feedback (Fig. 6, bottom right). It is difficult to closely match the items in Fig. 6 with the items in Fig. 4, but broadly speaking, the following correlation can be adduced. "Analysis" corresponds with problem setting and modeling, "function design" and "system design" with derivative analysis, "provision" with manufacturing, and "receipt" with evaluation and maintenance. In other words, this means that modeling of individuals is performed during the problem setting (corresponding to socialization technology) in "analysis" based on the receipt results in the step immediately prior to that. As described above, the outcomes of Phase II can be used in Fig. 6, bottom left. Figure 6, top left and bottom right are new themes that are dealt with in Phase III.

4.2 Related themes and remaining issues

We have also set other shared themes, some of which are listed below, and aim to achieve the objectives of RACE while solving them:

- New energy policies that take CO_2 emissions, promotion of energy conservation, and stable fuel supply into account.
- New staff education systems—training of industry oriented socialization skills.
- Concept of water demand predictions and emergency water supply systems that take account of citizens returning home at times of earthquakes.
- Nursing techniques self-study support system enabling nursing students to apply the appropriate nursing measures to a variety of patients.

Each of these themes represents typical examples of the "modern evils" outlined at the start of this paper—namely, the environment, wealth and poverty (education is an effective means of solving wealth and poverty problems), safety, and health—and can be said to be typical problems involving both the human aspect of modeling the individual, and the sociotechnological aspect of artifact creation by multi-stakeholders. We expect the solving of these problems to be a major outcome of Phase III.

The most important issue remaining is the problem of transdisciplinary deployment, that is, the question of how to apply a proposed solution for a given problem to other issues. Put in other words, the problem of how to accumulate knowledge that transcends the limitations of specific disciplines. In the current circumstances we believe that the first step toward solving this problem is to take a comprehensive view of the solution finding process while solving each problem, describe that in as universal a form as possible, and build a database.

5 Conclusion

This paper first outlined the current status and future concept of the study of artifactology. It then explained our objective to build continuous harmonious relationships between artifacts and individuals/society/environment, through an approach from the perspective of modeling of individuals and socialization technologies for artifact creation. It also outlined a scenario that applies techniques for modeling individuals with incorporated experimental economics techniques, and extracted the modeling of product service systems as an example theme.

From the perspective of strategic use of its limited human and material resources, Japan needs to concentrate on, and make choices in, both research and education. It is of vital importance that we as researchers not only proactively generate action and behavior in actual society, which also includes social collaboration, but also facilitate structures to promptly circulate any knowledge and information obtained during the process within that organization. The important aspect that must be considered at this time is that introduction of a new evaluation system for research organizations and researchers that incorporates evaluation from the perspective of outcome creation is of the essence. In future, this will require consideration of a new format for evaluating research

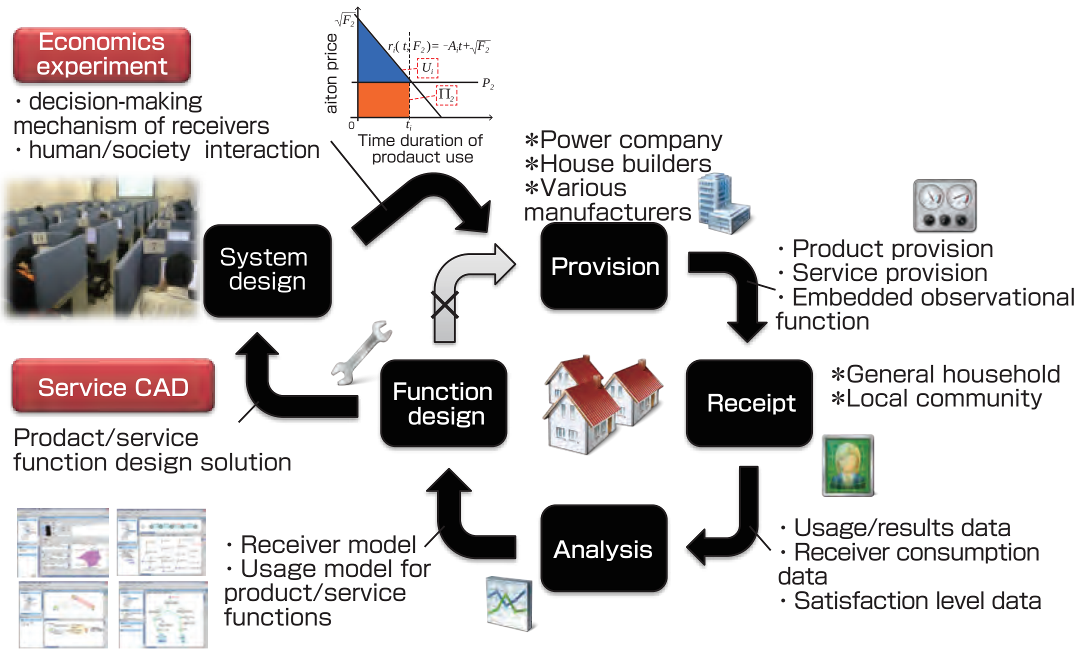

Fig. 6 Product service system concept for a smart house

outcomes.

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Authors

Jun OTA

Received B.E., M.E. and Ph.D degrees from the Faculty of Engineering, the University of Tokyo in 1987, 1989 and 1994 respectively. From 1989 to 1991, joined Nippon Steel Cooperation. Became Research Associate (1991), Lecturer (1994), Associate Professor (1996), the University of Tokyo. From April 2009, Professor, Graduate School of Engineering, the University of Tokyo. From June 2009, Professor, Research into Artifacts, Center for Engineering (RACE), the University of Tokyo. From 1996 to 1997, Visiting Scholar, Stanford University. His research interests are multi-agent robot systems, design support for large-scale production/material handling systems, mobiligence, human behavior analysis and support. He has contributed to constructing generalization of the thesis, and structure of overall/concrete contents.

Nariaki NISHINO

Received B.E. (1999) and M.E. (2001) in mechanical engineering from Kobe University, received Ph.D. in precision engineering from The University of Tokyo (2004). Postdoctoral fellow (2004-2005), Assistant Professor (2006-2009), Co-creation Engineering Research Division, Research into Artifacts, Center for Engineering (RACE), The University of Tokyo. Currently Associate Professor, Department of Technology Innovation, School of Engineering, the University of Tokyo. He is engaged in studies of artifact design considering aspects of social systems with the method of experimental economics and agent-based simulation. His research interests include game theory, mechanism design, network externality, management of technology, and product service systems. He is also active in collaborative research on decision-making problems with manufacturing and service industries in Japan. In this article, he contributed to a part of the methodology concerning socialization technology and explanation about the concrete theme.

Tatsunori HARA

Received B.E. (2004) in system innovation, M.E. (2006) and Ph.D (2009) in precision engineering from the University of Tokyo. Assistant Professor (2009-2011), Department of Precision Engineering, School of Engineering, the University of Tokyo. Currently Associate Professor, Human-Artifactology Division, Research into Artifacts, Center for Engineering (RACE), the University of Tokyo. His research interests include serviceology, service engineering, service design, product service systems, and tourism informatics. He has been working on development of a service CAD system called Service Explorer, which is a main deliverable of service engineering division in Phase of RACE. In this article, he contributed to a part of the methodology concerning modeling of individual and explanation about the concrete theme.

Toyohisa FUJITA

Director of Research into Artifacts, Center for Engineering, also Professor of Department of Systems Innovation, Graduate School of Engineering, the University of Tokyo. Was Professor, Akita University (1995-2003). Was President, Resources Processing Society of Japan, (2005-2009), President, the Research Forum on the Recycling Technology of Rare Metals from 2014. Themes of his research are recycling technology, mineral processing, environmental purification and preparation of intelligent fluids with nanotechnology. Received 30 awards from different kinds of societies. Also he has over 400 publications and submitted over 60 patents. He has contributed to the discussion on the total concept and direction in this paper.

Discussions with Reviewers

1 Overall content

Comment (Masaaki Mochimaru: Center for Service Research, AIST)

I understand that this article proposes a research framework centering on the discussion at the Research into Artifacts, Center for Engineering at the University of Tokyo, which performs a central role in the establishment of an artifactology framework and shaping of the methodology and direction in its further development, and outlines some examples of research activity based on this framework. Artifactology and *Synthesiology* share the same root, and the objectives of artifactology match the scope of the *Synthesiology* journal. I therefore think that the discussion of the research framework proposed in this article is useful for the readers of this journal, too.

However, I feel that the present composition does not form a paper on “new issues in artifactology and a new research framework for tackling these,” but rather is “an introduction of Phase III at the Research into Artifacts, Center for Engineering, the University of Tokyo.” As the formation of an “artifactology research framework” is the ultimate target this article must aim for, perhaps you could develop the argument for that.

Answer (Jun Ota)

Thank you for your valuable comment. I agree that the paper should be written more from a perspective of the development of artifactology rather than of the Research into Artifacts, Center for Engineering, the University of Tokyo. I have changed the structure in accordance with your suggestion.

2 The relation between Phase II and Phase III

Question (Motoyuki Akamatsu: Human Technology Research Institute, AIST)

The article explains the two divisions for socio-artifactology and human-artifactology that were established in Phase III, but although it mentions that both are “based on activities in Phase II,” the relation between Phases II and III is not clearly explained. I would like the hypothesis formation process that deemed the initiative necessary to be described, e.g., why were multi-stakeholder problems or problems in searching for a solution where the problem specification is incomplete not handled by life cycle engineering or co-creation engineering; or did it surface as an important issue in the practicing of life cycle engineering and co-creation engineering?

Answer (Jun Ota)

Phase II produced many research outcomes for design science based on physical science. In Phase III, we develop this to include the humanities/social sciences as subjects of study and also consider anything involved in human society. Against this background, we discuss socialization technology problems in connection with class III problems, as proposed by Professor Kanji Ueda. This problem was not sufficiently dealt with head-on in Phase II, but as our mission in Phase III is to solve a number of real-world problems and it is extremely important, we aim to deal with this problem and also systemize the problem-solving method. As the link between the outcomes for Phase II and Phase III was unclear, we have rewritten both descriptions to better reflect the difference. For instance, the description has been changed to make the outcome for the Value Creation Initiative Division the human sense of values. A concrete summary of Phase II outcomes has also been added (e.g., design of artifacts that take resource constraints and waste into consideration, and technology for a large-scale complex simulation base).

Regarding modeling of individuals, this was also dealt with in Phase II, but the main outcome was modeling of individual differences. As changes in the state of individuals, i.e., dynamics, were insufficiently dealt with in Phase II, we consider dealing with them in Phase III. This has been added to the paper.

3 Modeling of individuals

Comment (Motoyuki Akamatsu)

The article writes about modeling of individuals, but I was unable to grasp what this is based on just the description. Furthermore, the experimental economics approach is given as a case example, and I infer that it is employed as an experimental method to perform modeling of individuals, but no hypothesis is provided on what is a required condition for the modeling of individuals or what kind of functionality is made possible in the experimental system if this condition is met. I think that writing such hypotheses would enable readers to understand it as a concrete approach to achieve the center's mission.

Comment (Masaaki Mochimaru)

"Modeling of individuals" is an important term in the research approach in Phase III. However, the reviewer has not been able to form an explicit understanding of this "modeling of individuals."

Answer (Jun Ota)

Regarding modeling of individuals, we have firstly amended the description of the hierarchical structure. For simplicity's sake, individuals in one box are considered to be expressed in its lowest part, and these are modeled in the form of interaction between homogeneous elements in the top position of the box immediately below (each having an internal state, and for this state different values can be taken). In this case, the internal state of the elements and the differences in interaction form the diversity of the individuals, and its dynamics form the dynamics of the individual. On that basis, we treat the individuals as agents and perform modeling from the perspective of three processes, namely, recognition of individuals, activities of individuals based on recognized results, and value construction of individuals, which underpins the generation of these activities. The aforementioned interaction is mainly expressed in the steps of recognition of individuals and activities of individuals, and the interaction and mediation among multi-stakeholders can then also be expressed. We have added an explanation to this effect. This is modeling of individuals.

Regarding the experimental economics approach, modeling is easy in the case of singular agents since behavior is rationality based, but in the case of multi-stakeholder systems, because of the interdependence of each agent's values, how each agent behaves is not well understood. Methods in experimental economics contribute to the model development of that aspect. Through experimental economics the experimenter induces specific utility functions in the subject, observes the behavior within a virtual social system where even utility is controlled, and, by looking at each actor's utility change and overall social surplus, it becomes possible to deal with this explicitly as value. This method enables the modeling of the process of "value construction of individuals" outlined in chapter 2. This has been added to the paper.

4 Socialization technology

Comment (Motoyuki Akamatsu)

As the initiative in Phase III centers on explaining experimental economics research, I think the approach of research relating to socialization technology has not been emphasized in concrete terms. As this is research that will be conducted from now onward, I do not think it can be easily organized along the lines of the framework, but for the reader to understand this emphasis it is desirable that it is adjusted to the extent that the overall article is organized in a logical manner.

Answer (Jun Ota)

As you have pointed out, the paper contained little discussion of socialization technology and we have therefore made an addition to this effect. Multi-stakeholder environments themselves are considered to be strongly linked to socialization technology. We have described the correspondence relation in figures 4 and 6. "Analysis" corresponds to problem setting, "function design" and "system design" to derivative analysis, "provision" to manufacturing, and "receipt" to evaluation and maintenance. This means that modeling of individuals is performed while problem setting (corresponding to socialization technology) is conducted based on the results received in the step immediately prior to "analysis."