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SEMIOTIC BASIS FOR DESIGNING PRODUCT ARCHITECTURE

Fei HU (1), Keichii SATO (2), Xi ZHANG (3), Taiping ZHU (3)
1: Guangdong University of Technology, People's Republic of China; 2: Illinois Institute of Technology, USA; 3: Wuhan University of Technology, People's Republic of China

ABSTRACT
On modular product architecture, use related issues such as usability and interactive experience have not been addressed enough in product architecture. This paper introduces a conceptual framework "Semiotic Approach to Product Architecture Design (SAPAD)" to incorporate how users embed, develop and interpret meaning and values in product use. In this framework, three dimensions of human-product interaction are introduced. The first is user behavior dimension that represents activity, process, action and operation; the second is object dimension that represents ensemble, object, unit and component. The third dimension represents significations that includes six worlds based on the concept of Semiotic Ladder by Ronald Stamper, which are physical world, syntactic world, empiric world, semantics world, pragmatics world and social world. A case study was conducted to develop a SAPAD model on Oolong tea making activity in a Chinese household. The case study demonstrated that SAPAD can effectively reflect semiotic aspects of the use process on the product architecture that leads to the enhancement of meaningfulness and effectiveness of the product in real use situations.

Keywords: meaningful experience, signification architecture, product architecture, semiotic ladder, user-product interaction

Contact:
Prof. Fei Hu
Guangdong University of Technology
School of Art & Design
Guangzhou
510090
People's Republic of China
philhu2002@gmail.com

1 INTRODUCTION

Although the concept of user experience has been already addressed in a wide range of design areas including product, environment, service, and software, the interaction experience between human and product has not been well explained with theoretical models or effective methodologies. Even basic problems of product use that were described by Norman (1988) still frequently appear on everyday things as well as on industrial systems.

The theories on modularity and product architecture had already been discussed comprehensively. But user experience is still not discussed sufficiently in those researches. This paper tries to incorporate the signification and experience in user-product interaction, and find a new way for designing product architecture based upon user significations.

2 LITERATURE REVIEW ON PRODUCT ARCHITECTURE

Ulrich (1995) articulated five potential application areas of product architecture: 1) product change; 2) product variety; 3) component standardization; 4) product performance; 5) product development management. Rosen (1996) and Sosa (2000) developed it as a form-based method. Zamirowski and Otto(1999), Stone, Wood, and Crawford(2000) developed it as a function-based method. Both researches provided conceptual and methodological foundation for implementing product family strategies and methodologies (Erens and Verhulst, 1997; Dahmus, Gonzales-Zugasti and Otto, 2001; Martin and Ishii, 2002; Kariman and Herrmann, 2009). Product architecture was also a fundamental mechanism for product lifecycle design (Rosen, 1996; Wyatt, Wynn and Clarkson, 2009). Further, Antonsson and Cagan (2001) and Chakrabarti (2002) looked it as a general mechanism for design synthesis method.

As the importance of user-centered design (UCD) more recognized, in a wide range of design areas, product architecture research also addressed its importance. Yu, Gonzalez-Zugasti and Otto(1999) defined product architecture based on customer demands. The framework of User Process based Product Architecture (UPPA) by Teeravarunyou and Sato (2001) translated use processes and users' knowledge in a variety of use contexts into product architecture as a platform for product variation management and mass customization. Galvao and Sato (2004) introduced a framework that consisted of multiple inter-related knowledge sets for representing users' mental models in relation to product structure and function, and users' procedures and context-of-use. Further, Galvao and Sato (2005) discussed affordance based approaches to product architecture and developed a product-affordance-user model in functional and operational levels in order to reveal the relationships between technical functions and user tasks.

Along this way, this paper tried to seek richer significations and implications in the user-product interaction, and build specific and explicit connections between user experience and product architecture. Obviously, Semiotics frameworks could provide clear and general references, especially in the theories on meaning and experience.

3 PERSPECTIVE OF SEMIOTIC FRAMEWORKS

Semiotics is a study on meaning and its role in human activities and environments and how it is created, represented, communicated or interpreted through signs. According to De Saussure the sign is composed by a “signifier”, the form which the sign takes, and a “signified”, the concept it represents. C.S. Peirce's concept of semiotics consisted of three parts: 1) Representamen: the form which the sign takes, 2) Interpretant: the sense made of the sign and, 3) Object: to which the sign refers or alludes. Morris (1946) defined Semiotics as the science of signs and introduced three types of relations called semantics, syntactics and pragmatics. Semantics concerns sign-object relations, pragmatics concerns sign-interpretant (persons) relations, and syntactics concerns sign-sign relations. Nauta (1972) built a Semiotic Cube to illustrate an unified framework of Peirce's trichotomy of icon-index-symbol and Morris's trichotomies of syntactics-semantics-pragmatics. Semiotic Ladder framework by Stamper (1996) added three new views on signs from the perspective of physics, empirics and social world in addition to the three aspects of signs distinguished by Morris. The addition of a view on information from the social world stresses that information use is always a part of human behavior in a social setting, where norms or social conventions governed people’s behaviors. Stamper developed Organizational Semiotics to seek new and useful ways to understand human information and

communication systems from an organizational perspective. Further, Cordeiro and Filipe (2004) built a Semiotic Pentagram Framework (SPF) in order to solve some of the problems and criticism posed on Semiotics Ladder.

In Table 1, several Semiotics frameworks are compared. Although three semiotics divisions by Morris had been a subject of some criticism (Halton, 1992), and there were some controversies about Semiotics Ladder, such as confusion between the empirical and the physical level (Ågerfalk, Karlsson and Hjalmarsson, 2002), Semiotics Ladder is regarded as a relatively reasonable and constructive framework for complex technical and organizational system design.

Table 1 Several Semiotics frameworks

Morris's semiotics divisions	Nauta's Semiotics Cube	Stamper's Semiotics Ladder	SPF Views	Concerns
		Physical	Physical View	Physical aspects
		Empirical		Statistical properties
			Object of analysis	Sign systems, semiospheres, texts
Syntactic	icon-syntactics-pure	Syntactic	Relational View	Structure
Semantic	index-semantics-descriptive	Semantic	Interpretational View	Meaning
Pragmatic	symbol-pragmatics-applied	Pragmatic	Communication View	Usage and communication
			Work View	
		Social world	Human Circle	Social aspects

4 PERSPECTIVE OF SEMIOTIC FRAMEWORKS

User-product interaction can be seen in two interactive dimensions: one is user behavior, and the other is object. User behavior dimension has four hierarchical levels, activity, process, action and operation, and object dimension has four levels, ensemble, object, unit and component as depicted in Figure 1. The highest level, ensemble includes all of objects in an activity, and objects are used in a process enabling task in this process. Each object can be divided into several units according to different goals, and each unit is composed of components.

The third dimension is user signification. Based on Semiotic Ladder framework by Stamper (1996), six levels of user signification are: 1) Physical level is about "what" in physical attribute, which is related to function, such as material, signals, traces, and physical distinctions. 2) Syntactic level is about "how" to connect each other between function modules, which focus on structure, logic and usability, such as formal structure, language, data, records and deduction. 3) Empiric level is about "how" in human-computer/product interaction, such as operation, control and skill between user and object. 4) Semantic level is about "why" to interact between individual and object, such as emotion, personality and persuade. 5) Pragmatic level is about "how" to communicate in interactions, which focuses on sub-culture and group identity, such as intention, transmission, conversation, negotiation; 6) Social level is about the social and cultural factors in the interaction, which focuses on value and ideology, such as beliefs, expectation, commitment, contract, law, and cultural convention.

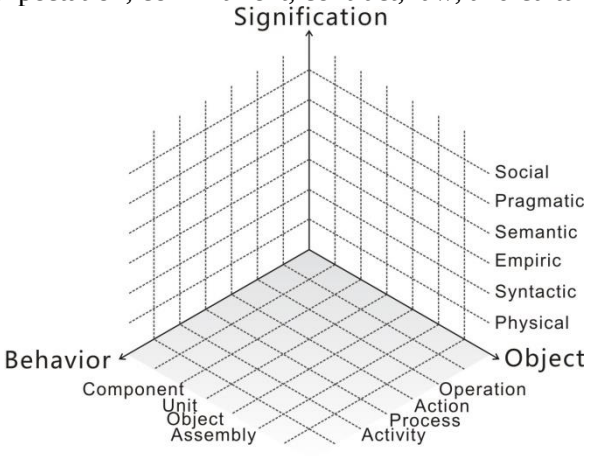


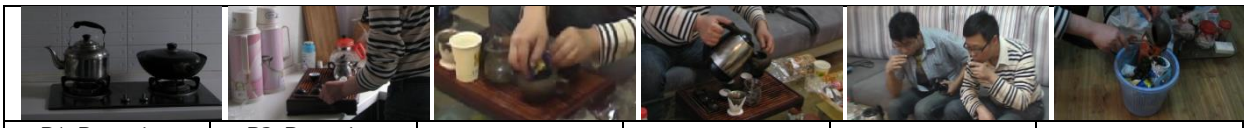
Figure 1 Three dimensions of SAPAD

A three dimensional model of Semiotic Approach to Product Architecture Design (SAPAD) is represented in Figure 1. The relationship between user behavior dimension and object dimension is relatively clear and definite; however, the six levels of user signification still cannot be mapped onto other dimensions. In order to examine the relationships, a case study was conducted on Oolong tea making by Chinese people at home.

5 CASE STUDY: OOLONG TEA MAKING AT HOME

5.1 Observation and User Behavior Analysis

Observation study was conducted to capture the activities in Oolong tea making and tasting processes. There were two roles of participants, one was a host performed by a 37-year-old male, and the other role was a visitor served with tea by the host. The event took place in the host's mid size apartment unit with contemporary style interior during the period of 4:00 pm- 5:00 pm. The activity of making Oolong tea at home could be divided into six sub-processes as shown in Figure 2: 1) preparing water, 2) preparing tea equipages, 3) preparing tea, 4) making tea, 5) tasting tea, 6) cleaning.



P1. Preparing Water	P2. Preparing equipages	P3. Preparing Tea	P4. Making Tea	P5. Tasting Tea	P6. Cleaning

Figure 2 Six processes of Oolong tea making activity

cabinet	gas stove	kettle	trough	tap	water	tea table	tea brewing tray	tea pot
tea pitcher	tea cup	strainer	tea container	tea packet	tea leaves	tongs	tea towel	garbage can

Figure 3 Objects in Oolong tea making activity

5.2 Action-Object-Signification Analysis

Oolong tea making is a very complicated activity, which involves eighteen objects as shown in Figure 3. The relationships between actions, objects and significations were identified in Table 2. Pi's in the table represent six sub-processes introduced in the previous section. Next, the researchers analyzed potential significations in each action at physical level, syntactic level, empiric level, semantics level, pragmatic level and social level. After an interview with the participants to avoid misunderstanding of their behaviors, eleven signification factors represented as Si in the table were identified in this activity: 1) cleaning; 2) economy; 3) recreation; 4) experience; 5) convenience; 6) carefulness; 7) at-will; 8) self-expression; 9) knowledge; 10) etiquette; 11) elegance.

5.3 Signification Analysis

Based on the cluster analysis, five signification modules were formed in three levels: 1) in the pragmatic and social level, etiquette and self-expression were core signification factors; 2) in semantics level, the significance module of elegance, relaxation and at-will, the significance module of carefulness and cleaning, and the significance module of convenience and economy represented the personality and characteristic of the user; 3) in empiric level, experience and knowledge were the basis of this activity.

5.4 Signification Analysis

According to these signification modules, key objects were identified in each level. In the pragmatic and social level, the key objects included tongs(3), tea brewing tray(2), tea pot(1), tea container (1), tea leaves (1), tea pitcher (1) and tea cup(1). In the semantic level, the key objects included tea towel(3),

gas stove(2), tea cup(2), tea table(2), trough(1), cool water(1), tea leaves(1), cabinet(1), tea brewing tray(1), tea pitcher (1) and tea container(1). In the empirics level, the key objects included boiling water(2), tea cup(2), tea leaves(2), tap(2), gas stove(1), tea towel(1), tea brewing tray(1), cabinet(1), Tea packet(1) and tea pot(1).

Table 2 Key object in each action

.	Actions	Objects related to actions	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
P1	1.1 pouring water	kettle, tap, cool water, trough	○	○		○							
	1.2 boiling water	kettle, tea towel, gas stove			○	○	○						
	1.3 taking kettle to living room	kettle, tea towel, tea table	○	○		○		○	○			○	
P2	2.1 taking out tea set	cabinet, tea brewing tray, tea pot, tea cup, tea pitcher, strainer, tongs	○		○			○			○		
	2.2 washing tea set	tap, boiling water, tea brewing tray, tea pot, tea cup, tea pitcher, strainer, tongs, trough	○					○				○	
	2.3 putting tea set on tea brewing tray	tea brewing tray, tea pot, tea cup, tea pitcher, tongs, cabinet								○		○	
	2.4 bringing tea set to living room	tea brewing tray, tea pot, tea cup, tea pitcher, strainer, tongs, tea table										○	
P3	3.1 taking out tea packet	tea container, tea table, tea packet					○				○	○	
	3.2 opening tea packet	tea packet											
	3.3 putting tea leaves	tea leaves, tea pot											
P4	4.1 washing tea leaves	kettle, boiling water, tea pot, tea leaves				○				○		○	
	4.2 warming tea cup	kettle, tea pot, tea pitcher, strainer, tea cup, tongs				○						○	
	4.3 infusing water	kettle, boiling water, tea pot				○							
	4.4 watching	tongs, tea pot, tea leaves				○			○				
P5	5.1 placing strainer	strainer, tea pitcher											
	5.2 infusing tea to tea pitcher	tea pot, strainer, tea pitcher				○							
	5.3 pouring tea to tea cup	tea pitcher, tea cup										○	○
	5.4 taking tea cup up and tasting	tea cup, tea leaves			○						○	○	○
P6	6.1 cleaning tea leaves	tongs, tea pot, tea leaves, garbage can		○							○		
	6.2 washing tea set	tap, cool water, tea brewing tray, tea pot, tea cup, tea pitcher, strainer, tongs, trough									○		
	6.3 putting tea set back to cabinet	tea brewing tray, tea pot, tea cup, tea pitcher, strainer, tongs, cabinet				○							

	economy	convenience	at-will	recreation	elegance	experience	knowledge	self-expression	etiquette	cleaning	carefulness
economy	1										
convenience		1				1					
at-will			1	1							
recreation			1	1	1						
elegance				1	1		1	1			
experience		1				1	1	1	1		
knowledge					1	1	1	1	1		
self-expression					1	1	1	1	1	1	
etiquette						1	1	1	1	1	
cleaning								1	1	1	1
carefulness										1	1

Figure 4 Signification architecture & Signification modules

5.5 Object Architecture based on Signification Modules

In the pragmatic and social level, three object modules were identified: 1) tea leaves storing module included tea leaves, tea container and tea table; 2) self-expression module included tea table, tea pot,

tea pitcher, tea brewing trey and tea cup; 3) auxiliary module included tea cup and tongs (Figure 5).

	tongs	tea cup	tea brewing tray	tea pot	tea pitcher	tea table	tea container	tea leaves
tongs	1	1						
tea cup	1	1	1	1	1	1		
tea brewing tray		1	1	1	1	1		
tea pot		1	1	1	1	1		1
tea pitcher		1	1	1	1	1		
tea table		1	1	1	1	1	1	
tea container						1	1	1
tea leaves				1			1	1

Figure 5 Object architecture & Object modules in the pragmatic and social level

In the semantic level, five object modules were identified: 1) heating module including a gas stove; 2) pre-cleaning module including cold water and a trough; 3) tea set storing module including a cabinet, tea cups, a tea pitcher, and a tea brewing tray; 4) cleaning module including tea brewing tray, a tea towel and a tea table; 5) tea leaves storing module included a tea table, a tea container and tea leaves, as shown in Figure 6.

	gas stove	cool water	trough	cabinet	tea cup	tea pitcher	tea brewing tray	tea towel	tea table	tea container	tea leaves
gas stove	1										
cool water		1	1								
trough		1	1								
cabinet				1	1		1				
tea cup				1	1	1	1				
tea pitcher					1	1	1				
tea brewing tray				1	1	1	1	1	1		
tea towel							1	1	1		
tea table							1	1	1	1	
tea container									1	1	1
tea leaves										1	1

Figure 6 Object architecture & Object modules in the semantic level

	tea towel	gas stove	tap	Tea packet	tea leaves	boiling water	tea pot	tea brewing tray	tea cup	cabinet
tea towel	1									
gas stove		1								
tap			1							
Tea packet				1	1					
tea leaves				1	1	1	1			
boiling water					1	1	1			
tea pot					1	1	1	1	1	1
tea brewing tray							1	1	1	1
tea cup							1	1	1	1
cabinet							1	1	1	1

Figure 7 Object architecture & Object modules in the empirical level

In the empirical level, five object modules were identified: 1)cleaning module included tea towel; 2) heating module included gas stove; 3) water supplying module included tap; 4) tea brewing module

included tea packet, tea leaves, boiling water and tea pot; 5) tea set storing module included tea brewing tray, tea cup and cabinet, as shown in Figure 7.

5.6 Design Opportunities

Finally, eight modules were confirmed as pre-cleaning module, heating module, auxiliary module, tea set storing module, cleaning module, tea making module, tea leaves storing module and self-expression module. The relationships among eighteen objects in these modules were shown in Figure 8 (left). It was obvious that tea making module, tea leaves storing module, self-expression module and tea set storing module were very close each other, and self-expression module and tea set storing module were almost identical. From the signification analysis in Figure 4, the key of this activity is not to quench thirst or care health for himself, but to express etiquette and himself to the visitors, which is just a desired and unmet need. So a potential system boundary for a new product appeared clearly. There should be an integrated tea table system that provides multiple functions such as storing, tea-making and representing the host, as shown in Figure 8 (right).

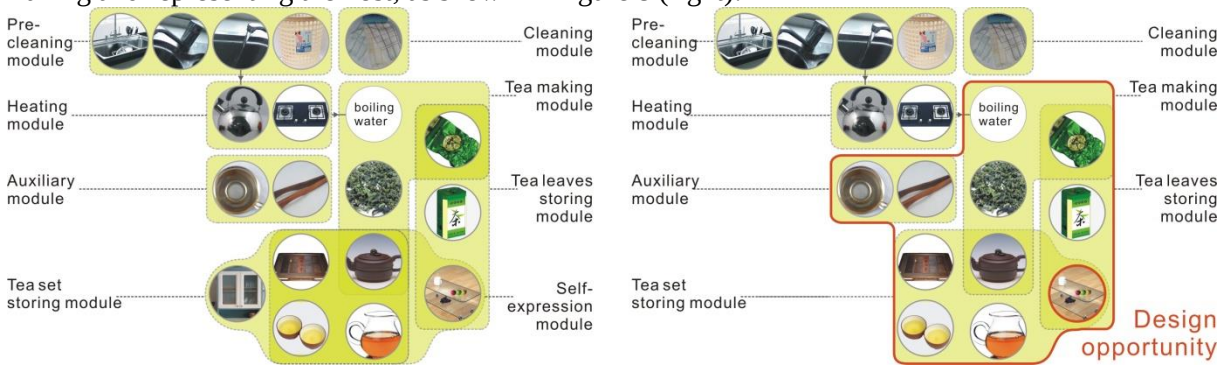


Figure 8 Design opportunity

5.7 Product Modules in the Syntactic & the Empirical levels

Further, the researchers have analyzed the signification in each action and component at the syntactics level and empirics level. The function requirements from the syntactics level included: 1) adjust, including water faucet and power switch of gas stove; 2) transport, including tap, kettle, running water pipe, tea pot and tea brewing tray; 3) store, including tea brewing tray store waste water, tea cup, the door of the cabinet and tea container; 4) supply/filter, including water, boiling water, gas stove, garbage can and trap valve; 5) heat-insulating, including tea pitcher, tea cup, handle of kettle and tea towel as shown in Figure 9.

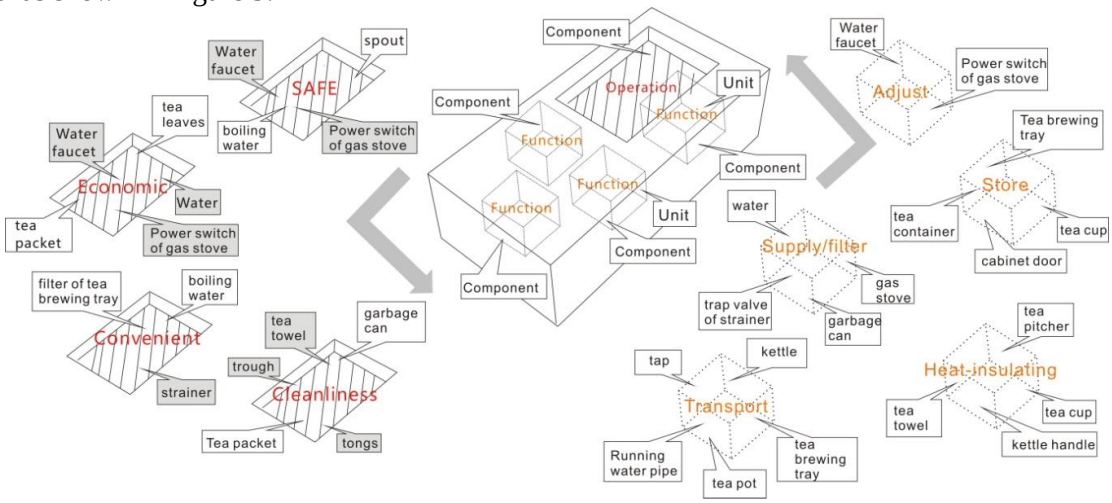


Figure 9 Function modules in the syntactics level and the empirical level

In the empirics level, the significations on user's actions included: 1) safety, including water faucet, power switch of gas stove, spout and boiling water; 2) economics, including water faucet, power switch of gas, water, tea packet and tea leaves; 3) cleanliness, including trough, tea towel, tea packet, tongs and garbage; 4) convenience, including boiling water, filter of tea brewing tray, strainer and tongs as shown in Figure 9.

5.8 New Product Development

Finally, the researchers developed an integrated tea table system, which had three units to store tea set, tea leaves and utensils. The tea set storing module came from the kitchen to the living room, which was not only more convenient, but also better for self-expression. Some Chinese style elements were used, which was not only for tea culture, but also master's taste. Besides, glass was used for the table in order to show the tea set in storage, which expressed himself more directly. Product design developed along the ways how to take tea set out, as shown in Figure 10.

Figure 10 Product design

6 CONCLUSION AND FUTURE RESEARCH

The core of product architecture is modularity. The meaning of the term modularity has changed from being defined by the physical presence to being defined by structure and function. Pahl and Beitz (1996) directly defined different types of modules based upon a range of functions (basic, auxiliary, special, adaptive). Today modularity is a combination of systems attributes, and has evolved in an industrial context (Miller, 1998). For whether creation of variety, utilization of similarities or reduction of complexities, modularity is still an effective approach to both product design and manufacture.

Along the concept of modularity, this paper used signification mechanisms in user-product interaction, in order to develop architecture for products and services from users' perspectives. In the framework of Semiotic Approach to Product Architecture Design (SAPAD), three dimensions were divided into several levels: four levels of user behavior dimension were activity, process, action and operation; four levels of object dimension were ensemble, object, unit and component; and six levels of user signification dimension were physical level, syntactic level, empirical level, semantics level, pragmatic level and social level.

In the case study of Oolong tea making activity at home, rich significations appeared in user activity, and were projected into twenty-one actions and eighteen objects correspondingly. Four levels of significances were discussed and emphasized in this case study. The core and crucial meanings were etiquette and self-expression in the pragmatic level and social level. The different significances in the semantics level reflected the personality and diversity of the users, such as elegance, relaxation and at-will, carefulness and cleaning, convenience and economy. And there were common experience and knowledge of users groups in the empiric level. More important, different significations kept closely connection to different objects and units, which seemed to find a new possibility for product architecture.

It was obvious that significations emerged synchronically. The relationship between user behavior and user significance was not a simply one-to-one mapping, while the six levels of user significances clearly matched user behavior, as shown in Figure 11. SAPAD framework focused on not only functions and manufactures, but also such significations as emotion, personality and value. In this case study, core significations were etiquette and self-expression, because making Oolong tea is an activity full of Chinese traditional culture. Later, the researchers developed new designs around how to express culture and taste of oneself, and how to express etiquette and respect to the guests.

Diller and Shedroff (2008) defined fifteen core meanings in their experience design framework, namely accomplishment, beauty, creation, community, duty, enlightenment, freedom, harmony, justice, oneness, redemption, security, truth, validation, and wonder. This case study identified the two significant factors, etiquette and self-expression, which were not included in the list by Diller and Shedroff although security, truth, and validation are somehow related with etiquette and self-expression.

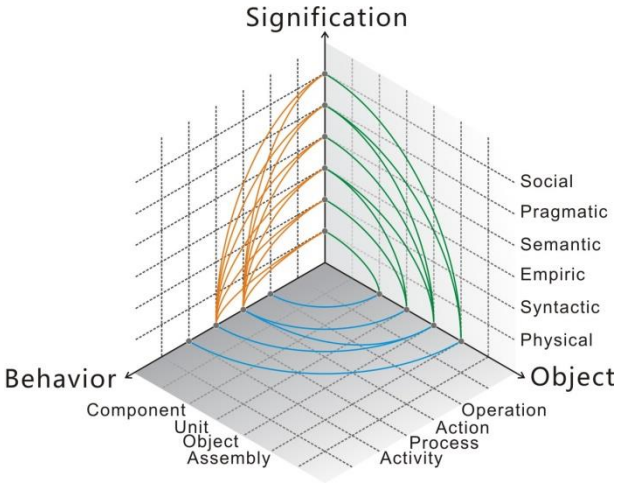


Figure 11 SAPAD framework

Although this case study was not complete, SAPAD framework demonstrated its effectiveness for examining signification mechanisms in user behavior, and for guiding architectural design of products and services. Signification mechanisms need to be further investigated at physical and syntactic levels, in order to construct a more comprehensive conceptual foundation for SAPAD. More case studies need to be conducted not only on culturally significant activities but also on other types of daily activities. As previous research and this research indicate, there are many different bases for designing product architecture. Further research needs to be developed for integrating different bases for optimizing architectural design in order to achieve the goals set for each product development project.

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