Collaborative product design processes of industrial design and engineering design in consumer product companies

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This study aims to elucidate how industrial designers and engineering designers collaborate, and how such an alliance reflects in the design process. We conducted in-depth interviews about actual product design projects with 34 industrial and engineering designers from six consumer product manufacturers. We firstly identified individual design processes from the interview data. Secondly, we then compared and merged the design processes into collaborative processes using a mosaic method. We finally simplified the collaborative processes to create representative process models. As a result, we discovered four types of typical collaborative product design processes and their characteristics – Type 1: ID-led Concept-driven Process, Type 2: ID-led Combined Outside-inside Process, Type 3: ED-led Inside-first Process, and Type 4: ID&ED Synergetic Process.

Keywords: design process modelling, collaborative design, product design, industrial design, engineering design

Integrated contribution of engineering design and industrial design is essential to launch successful products to the market. Product design can hardly be explained from a mono disciplinary perspective. However, it is known that engineering design and industrial design have considerably different design practices (Pei, 2009; Persson & Wickman, 2004), and their design approaches are in some ways opposite to each other (Eder, 2013; Hosnedl, Srp, & Dvorak, 2008; Pahl, Wallace, & Blessing, 2007). The industrial designers' role includes enhancing user experience of a product and developing its outside form and interface (Ulrich & Eppinger, 2012). They employ knowledge and skills in aesthetics and ergonomics (Eder, 2013; Pahl et al., 2007). Under the interaction with industrial designers, engineering designers take part in implementing the design concept developed by industrial designers (Persson & Warell, 2003). Engineering designers provide a means for the product to be functioning, reliable, and manufactured (Hubka & Eder, 2012; Pahl et al., 2007). This leads to different approaches

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www.elsevier.com/locate/destud
0142-694X *Design Studies* **46** (2016) 226–260
http://dx.doi.org/10.1016/j.destud.2016.06.003

between industrial and engineering designers (Cross, 2008; Hubka & Eder, 2012).

It is often argued that engineering designers use an 'outward approach – developing from function to appearance' whereas industrial designers follow an 'inward approach – developing from appearance to functions' (Eder, 2013; Hosnedl et al., 2008; Pahl et al., 2007). With these notions, the following two design strategies were proposed: one is the 'inside-out' strategy that is defined as designing the inner working parts first, and thus constraining the outside shape, and the other is the 'outside-in' strategy where the envelope was defined first, and thus constraining the inside parts (Hubka & Eder, 2012; Kim & Lee, 2010). These design strategies refer to combined design processes that a company should take for a specific purpose with particular conditions. However, little is known from empirical evidence about how these two strategies are applied in projects in industry. There have been few attempts to view the design process from an integrative perspective of engineering design and industrial design. In this regard, we investigated the collaborative design processes of both disciplines in the industrial context.

The research questions were: 1) what types of collaborative product design processes exist, and 2) what conditions drive a company to adopt a particular type of process. Based on the two designer groups' roles and characteristics, we hypothesized that there would be different types of outside-in and inside-out design approaches. We assumed that the outside-in approach would be characterized by an industrial design-led design process, thus generating industrial designer's role as a requirement and criteria provider, and the inside-out approach would be an engineering design-led design process, where engineering designers restrict industrial designer's task range by providing initial requirements for industrial designers' responsibilities. In order to succeed in a highly competitive market, companies should create collaborative processes of industrial design and engineering design by properly adopting outside-in and inside-out approaches to match their situations and objectives.

This paper serves two goals: firstly, to shed light on the form of the original collaborative product design process applied in practice, and secondly to determine different types of processes used for different purposes under different conditions. For these purposes, we conducted in-depth interviews with industrial designers and engineering designers from six consumer product manufacturers. We determined each company's product design processes using a '*mosaic method*,' where individual design processes drawn from interview data were combined to complete a collaborative process. As a result, we identified four types of typical collaborative product design processes and their characteristics.

The recurring term '*collaborative product design*' throughout this article refers to a product design created by the collaborative contribution of industrial design and engineering design. In particular, in corporate contexts, collaborative product design involves a series of design activities, such as the creation of initial product concepts, decisions on interior specifications, and the development of outer forms and inner structure. Hence, '*collaborative product design process*' means the product design process in which both industrial design and engineering design are directly involved in product development activities.

'*Industrial design*' at this point mostly concerns developing the outer forms, interfaces, and user experience of consumer products, excluding graphic-only or styling-only design. '*Engineering design*' develops technical solutions for placing and operating internal functional parts in consumer products and defines internal and external parts constituting products in a way that enables mass production. We labelled engineers engaged in such activities as '*engineering designers*'.

This article consists of three parts: The first part describes the research approach in detail. The second part presents typical collaborative product design processes and their characteristics as findings. Finally, it summarizes the results, and discusses the implications and contribution to the design literature.

1 Research approach

To investigate the types of collaborative product design processes and related conditions, we adopted a grounded theory approach in data collection and analysis (Charmaz, 2006; Glaser & Strauss, 2009), and a '*mosaic method*' that we devised to reconstruct collaborative design processes between industrial designers and engineering designers. The grounded theory approach is widely used in social sciences as a systematic methodology to establish theory for less studied areas, while in design research it has been long adopted (e.g. Lee & Cassidy, 2007; Wong, 2010). It uses inductive logic, starting with data collection mostly through in-depth interviews and/or observation. In the coding stage, there are generally two strategies. One is to collect and encode meaningful references from the data, and group them into coding categories when research topics are not clearly defined. The other is to use predefined coding categories in line with a particular theme to identify related references when research topics are clearly defined. We used the latter strategy, because the design process has been widely studied. Adopting a similar method, Berends, Reymen, Stultiens, and Peutz (2011) investigated the design processes of five companies. Kleinsmann and Valkenburg (2003) collected stories about collaborative design processes in industry and identified key themes and plots of the collaborative design projects.

We firstly conducted in-depth interviews with individual designers and collected their stories about design projects. To avoid a possible distortion due to the unreliability or possible inaccuracy of retrospective accounts (Ackroyd & Hughes, 1981), we adopted three criteria for selecting research targets: (1) multiple companies in a similar product domain; (2) multiple participants from both engineering and industrial design departments; and (3) projects already completed through a whole product development cycle. We set the first criterion to improve the applicability of research results. Understanding and analysing project contexts improve the applicability of design processes and methods (Gericke & Blessing, 2012). Thus, investigating multiple companies with similar project contexts could provide better chances to apply the research results. With the second criterion, the data from multiple informants with different perspectives are complemented by each other to offset any potential bias (Miller, Cardinal, & Glick, 1997). Finally, in retrospective interviews, the design process can be determined through collecting and analysing the stories of design projects that are already completed through a whole product development cycle (Berends et al., 2011).

In order to reconstruct product design processes based on transcribed interview data, we firstly identified '*process elements*' and then drew out partial design processes that individual designers practiced. Next, we combined all partial processes in each company into collaborative product design processes using the '*mosaic method*.' After constructing all detailed collaborative product design processes, we simplified them with '*process chunks*' to identify the types of typical design processes. Finally, we visualized them as design process models. Figure 1 shows the research procedure.

Actual design processes and their characteristics in reference to the context can be determined from actual design projects, which may be different from the documented design processes of the companies. Comparing both will provide insight. However, we could not collect them, because they are considered as confidential to the outside. Instead, we asked the interviewees whether their company has a documented standard design process and whether it is different from actual design processes.

1.1 In-depth interview

1.1.1 Selection of case companies

To increase the applicability, the design process should be understood within the context and environment of a company (Maffin, 1998). As such, we set three criteria by specifying case companies to explore. The three criteria adopted are as follows:

1) The companies should produce mid-complex electronic consumer products.
2) They should have independent industrial design and engineering design departments.

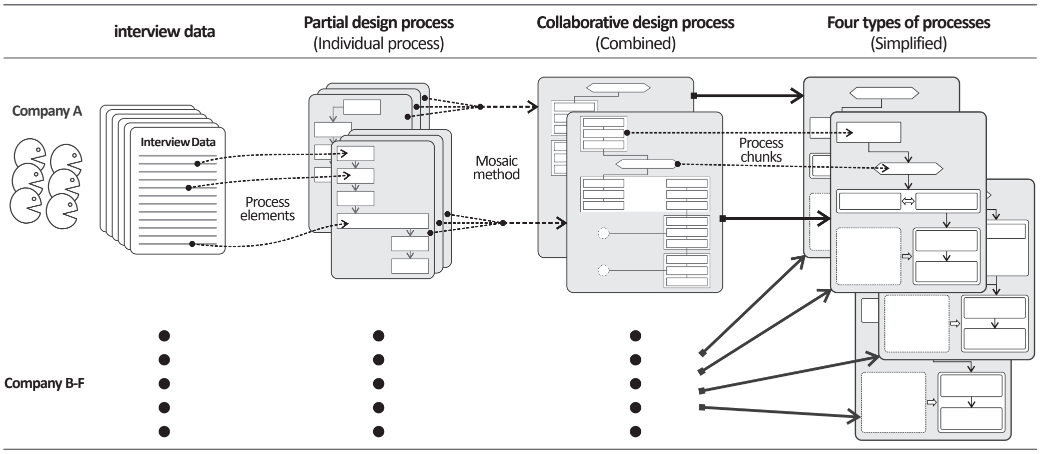

Figure 1 Research procedure

3) They should be leading companies in the market producing well-designed high-quality products.

The first criterion enabled the selection of manufacturers with similar in product domain context wherein both industrial designers and engineering designers play important roles. Manufactures producing simple consumer products will require a lesser role from engineering designers. In addition, developing a rocket needs no industrial designer's role. Ulrich and Eppinger (2012) stated that '*electromechanical products of modest complexity*' requires equally important roles of industrial designers and engineering designers. Based on the classification of engineered consumer products with complexity proposed by Cross (2008), examples of modest complex products are electrical drills and washing machines. Thus, mid-complex electronic consumer products refer to everyday consumer electronics goods that are engineered products fully integrating electronic and mechanical systems (Vasić & Lazarević, 2008). Although, the first criterion is satisfied, some companies such as Original Equipment Manufacturers (OEM), or small companies have either one department of industrial design or engineering design, or none. In such cases, they use external design and/or engineering consulting firms. Their collaboration process would be different from that happening between in-house independent industrial design and engineering departments. We intended to increase the applicability of research results by exploring cases with similar contexts. Thus, the second criterion was fulfilled. Finally, leading companies producing well-designed and high-quality products could provide reasonable and proper data for investigation, and the findings would be a good source of reference for other companies. Lawson (1994) pointed out that discovering how good design practices take place would be beneficial to understand and prescribe methods more effective. This is the rationale for third criterion.

We selected the case companies with the above criteria. We firstly applied first and third criteria to the list of the companies that had won the 'Korean Good Design Award' from 2006 to 2010 (About GD, 2011) consecutively. The 'Korean Good Design Award' is popular among many market-leading manufacturers in Korea. As a result, we obtained 16 company names. Then, we contacted each company with contact information in the awardee lists, and asked the gatekeepers if they had independent ID and ED departments (second criterion) and if they were willing to participate in the study. Finally, we selected six companies (Table 1).

1.1.2 Selection of interviewees

We selected interviewees with purposive and snowball sampling methods (Berg, 1988). The gatekeeper of each company suggested their designers who in turn suggested their co-workers. While doing so, we selected interviewees satisfying the three criteria below:

1) More than two years of experience in the company
2) Engagement in at least one cycle of the product development process
3) Close collaboration and interaction with counterparts (i.e. industrial designers vs. engineering designers)

The intended number of interviewees recruited from industrial designer and engineering designer groups in a company was six, with three from each to keep the balance. However we were able to recruit only two engineering designers each from Company B and F. In total, 18 industrial designers and 16 engineering designers participated as interviewees. Their working experience ranged from 2.1 to 20 years with an average of 8.9 years.

1.1.3 Interview procedure

We employed a semi-structured in-depth interview method following suggested instruction from the literature (Kvale & Brinkmann, 2009; Seidman, 2012). We firstly listed about 20 detailed questions and grouped them into four main themes: 1) personal information, 2) design process, 3) role and expertise, and 4) interaction.We then formulated four key questions:

1) What is your position and role in the team?
2) How did the product design process proceed and what happened during the process?
3) What tasks did you have in the design process, and what knowledge and skills you had required to carry out the projects?
4) How did industrial design(ers) and engineering design(ers) interact with each other during the design process?

The interview started with the first question about interviewees' roles in their teams and working experiences, followed by the product development

Table 1 Information of the case companies

Company	*Business area*	*Number of industrial designers*	*Number of engineering designers*
Company A	Home Appliances	10–20	50–100
Company B	IT Products	5–10	5–10
Company C	Mobile Communications	40–50	50–100
Company D	Mobile Communications	50–100	100–200
Company E	Security Devices	5–10	20–30
Company F	Home Appliances	5–10	30–40

processes they experienced and their tasks in such processes. When an interviewee hesitated to start talking because of inattention to specify a moment to recall, we provided a detailed context, e.g. '*Assume that today is the kick-off meeting day for the project you were involved in, and then tell me about what happened*.' This followed the advice for good questioning in an interview study; assuming, alternative, ideal, and interpretive questions (Merriam, 1998). To restrict inconsistencies caused by multiple interviewers, one author performed all the interviews (Ahmed, 2007). Moreover, the author had 14 years of industry experience in product development, which limited the possibility of misunderstanding the composed design situation described by interviewees. To avoid bias regarding the interviewer's experience, this research followed the '*Epoche*' process in which prejudgment and assumptions about a phenomenon are blocked in order to examine it in the world of participants (Leedy & Ormrod, 2012). Therefore, the interviewer ignored prejudgment on the phenomenon when feeling like judging the interviewee's response. We conducted the interviews in quiet rooms in each company, and audio-recorded all conversations. To help the conversation, and to record supplementary information, we made field notes. Sometimes, interviewees produced drawings on the note to provide a detailed description.

It is known from experience that 90 min is appropriate for in-depth interview time, because informants respond to the interview earnestly within this time and informants' responses tend to decrease as the time exceeds 90 min (Seidman, 2012). We had a planned interview time of 90 min following the guideline, but we did not control it. We closed interviews when we had enough data regarding the questions by observing that new information from responses is decreased. The 'voice detection recording function' in the recorder enabled us to pause recording with a silence for a few seconds and resume when the voice came back. The time of recording ranged from 70 to 100 min per interviewee with an average of 78.5 min for all participants. Therefore, the actual interview time per interviewee should be longer than the recording time. We transcribed all interview data verbatim. As a result, we obtained around 1000 pages of the overall transcription.

1.2 Identifying design processes

1.2.1 Identifying design processes that each individual experienced

Although, all transcribed data contained information related to design processes, they were all intermingled with other contents, including the situation and goal of the project, individuals' roles, necessary skills and knowledge, conflicts between actors, perceived images of each other, etc. We firstly formulated a coding framework by reviewing related literature to identify '*process elements*' that were used for constructing the design process. We confirmed them by perusing Company A's interview transcription several times. The two perspectives on process modelling, viewing processes as information processing and state-transition systems provide meaningful clues about coding categories of process elements for the modelling of a process.

In the information processing perspective, Browning, Fricke, and Negele (2006) viewed product development and its activities as a process of information collection, creation, interpretation, transformation, and transfer. Most product development activities require a set of input and produce as outcomes of activities, preliminary outputs, status reports, etc. (Browning et al., 2006). This viewpoint has been supported by an extensive literature on design process and organization (e.g. Burns & Stalker, 1961; Clark, 1991; Hubka & Eder, 2012). Ulrich and Eppinger (2012) described this as information necessary for the final outcome that is injected to transform a current design problem to the next problem to lower uncertainty, and thereby producing output until the final outcome is formed. This is modelled as a process of transforming a functional specification (input) into an artefact specification (output) (Takeda, Veerkamp, & Yoshikawa, 1990; Tomiyama & Yoshikawa, 1986). Browning and Ramasesh (2007) pointed out that process modelling with the perspective of information processing fails to capture full information flow because interaction is poorly understood. They argued the importance of identifying interactions between organizational units, because they incur dependency between activities that establish deliverable flow patterns. Conclusively, the basic elements of process modelling in this perspective are summarized as '*information flow*' with the IPO (Input–Process–Output) representation and '*interaction*' of organizational units (person, team, company, etc.).

In the state-transition perspective, Reymen (2001) described a design process as the process of moving one state to another by performing a task at each stage and evaluating design activities. This is consistent with stage-gate models, where design activity happens at each stage and design output of the stage is evaluated at design review whereby a decision is made among whether to go to the next stage, repeat the current stage or reject the project

(Cagan & Vogel, 2002; Ulrich & Eppinger, 2012). This perspective is advocated from most stage-based models (Wynn & Clarkson, 2005). A stage-based model is made up of action that is intended to perform a task, and a decision that is to intended to evaluate the outcomes of performing the task; the completion of which constitutes progression to the next stage (Jänsch & Birkhofer, 2006; Roozenburg & Cross, 1991). Besides this, information flow accompanying input and output happens when jumping up from one stage to another or linking between sub-processes (Lindemann, 2003; Ogot & Okudan-Kremer, 2004). The engineering design process model proposed by Pahl et al. (2007) demonstrates clear inputs and outcomes of each stage. The input of the first stage is 'task' and the outcome is 'specification' that goes into the next stage as an input yet again. In this way, the sequential developmental stages connecting inputs and outcomes are drawn out. Regarding the term 'task' and 'design activity', Pahl et al. (2007) uses 'task' to mean the initial starting point of the project different from 'task' executed at each stage. However, these two terms are used similarly to indicate performing design work, and thus there is a general consensus about the design process of connecting and proceeding tasks interdependently (Dorst, 2008).

Taken into the state-transition perspective, there are two activities: performing task and evaluating outcomes. Mostly, evaluation happens within a relatively short period of time to decide between 'go forward, repeat, or drop.' Hence, we named these kinds of activities (evaluation, design review, gate check, decision-making) as '*event*.' At this juncture, we have two coding categories; '*task*' and '*event*.' In conclusion, we can model a design process with four coding categories; '*task*,' '*event*,' '*information flow*,' and '*interaction*,' and can be represented with the connection of stages. At this point, a stage of a design process can be represented with 'input—task (design activity)—event (decision-making)—output.' The followings describe how to encode process elements with the above four coding categories.

- Task: Clear tasks that designers perform such as 'idea sketches,' '3D modelling', etc. A respondent said; '*Yes, I do rough sketches with a ballpoint pen to express my idea. Little colouring on it or scan it to retouch on Photoshop*.' We encoded this into a task category with the label 'idea sketch.'
- Event: After a particular task, an event (decision-making) proceeds, leading to the next action. A respondent said; '*We go to the mock-up company to make prototypes, and bring all two or three prototypes. A mock-up evaluation meeting is held with them. … (omit) … the engineers listen to the boss's criticism. The boss states this is this and that is that, then, if engineers have different ideas, they provide opinions …. (omit) … finally the one is selected.* We encoded this with the label, 'mock-up evaluation meeting,' in the event category.

- Information Flow: Information flow is generated when a task or an event happens. It is always accompanied by input and output. A respondent said; '*In fact, we work based on specifications received from engineering designers. We don't start our work until something arrives*.' This describes that the industrial designers received 'specification data' from engineering designers as an input, with which they started their work. We encoded this 'specification data from ED to ID.' Another excerpt is; '*... when one is selected, we pass the 3D Data of the mock-up to the engineering department. ... (omit) ... we send 'STEP' files, then they use 'UG' to start design*.' This describes that they sent 3D CAD data as the output of their design activity to engineering designers, which become an input for the following engineering design activity. We encoded this '3D CAD data from ID to ED.'
- Interaction: When a task or event takes place, the two groups frequently interact. For example, while industrial designers checked whether the inside space could be modified, engineering designers advised them by providing related information. In such cases, intensive interaction happens and the engineering designer serves as an 'advisor.' A response is the case; '*They explain 'this should be placed here and that should be placed there.' Then, we modify the size and position and ask them again whether the 2-mm gap can be reduced. If they say 'Yes,' we flatten one part against another*.' We encoded this as 'advisor role of ED to ID.'

We identified process elements from every piece of transcribed interview data. We labelled them with the participant's own word as far as possible. We used the field notes as a supplementary data source. While doing so, we arranged and connected the encoded elements in a flowchart format chronologically to construct partial design processes. This method is widely adopted to visualize process models in industry (Vergidis, Tiwari, & Majeed, 2008). We also determined the project types and goals involved in the design processes from the interview data. Two researchers executed the whole procedures. One researcher firstly constructed partial design processes, and the other researcher examined them by inspecting the interview data. As a result, we obtained 45 partial design processes with 7–9 from each company (see the second row in Table 2).

1.2.2 *Identifying collaborative product design processes*

The next stage was to combine each company's design processes into collaborative design processes via a '*mosaic method*.' We firstly collected partial design processes from a particular project in a company. This was easily done because designers in a company described shared experiences in the same projects, whereby the individual partial design processes overlapped and supplemented each other. After that, we combined the partial processes by comparing and merging process elements. The partial processes extracted from industrial designers' interview data provided rich information on industrial design activities,

Table 2 Number of design processes identified

Company	*A*	*B*	*C*	*D*	*E*	*F*	*Total*
Number of partial design processes	9	7	7	8	9	7	45
Number of collaborative product design processes	3	1	2	2	3	1	12

including interactive behaviours with engineering designers but less information on pure engineering design activities. This was also the case for engineering design. We merged partial processes from industrial designers in a company to rebuild the design processes around industrial design activities. At the same time, we used the information provided by engineering designers to supplement and strengthen the design activity flows from the engineering design side. We rebuilt the design processes around engineering design activities in the same way. We finally merged the two design processes into one collaborative product design process. In the mosaic method, combining the crosschecked partial processes is beneficial for higher reliability and commonality. This significantly reduced the likelihood of constructing a process with incomplete information by offsetting each other's information. Thus, the '*mosaic method*' decreased the possibility of constructing an inaccurate process.

While comparing partial design processes, we found the product planning team was involved in some design process elements. Thus, we included its role. This implies that the product planning team plays a certain role in collaborative design projects of industrial design and engineering design. We also standardized some terms that indicated the same tasks or events. But, they were encoded differently because interviewees had used them slightly differently from each other. For example, we found that a meeting was encoded as '*Product Planning Meeting*' in one partial design process and '*Product Development Meeting*' in another. Thus, we unified them as '*Product Planning Meeting*.' Some also called the industrial design outcome differently such as '*mock-up*,' '*design mock-up*,' or '*mock-up fabrication*.' We unified them as '*design mock-up*.' We also standardized '*mock-up evaluation event*' and '*mock-up selection*' as '*mock-up evaluation event*.' This work was done by cross-checking interview data in each company while evaluating the meaning and context of the specific terms. Actually, designers seemed to understand each company's documented design process where standard terminology was defined, but were not particularly conscious of it. It seemed that they ignored the standardized process because the market situation was pushing them to move fast. Language difference is also a possible cause of the term difference. In the product design area, native words and borrowed words are mixed in use in Korea. For example, we use both borrowed words and native words indicating 'design' in English. Besides, cultural and locational differences of the two teams are likely to cause term difference. Except for Company F, the two departments were located in different physical spaces, at least on different floors.

Finally, we defined stages in a design process by merging stage elements (input, task, event, and output) into a box, and named them with related tasks (See Figure 2). For example, industrial designers start drawing various idea sketches based on research results of the previous stage. Then, they select a few best sketches through evaluation. According to the selection result, they decide to go to the next stage or repeat the current one. Therefore, the '*idea sketch*' stage is *composed of* '*research results* (input),' '*idea sketch* (task),' '*evaluation* (event),' and '*best sketches* (output).'

As a result, we obtained 12 collaborative product design processes from all companies; one to three from each company (see the third row in Table 2). We sent them to the informants of each company to check our interpretation of their processes. There were minor changes made in this process. Figure 3 shows a collaborative product design process of Company A. It shows two parallel processes on either side: an industrial design process on the left and an engineering design process on the right, with the interaction between the two illustrated in the middle. A '*product planning meeting*' in the middle is an event hosted by the 'product planning team,' where they make a decision, if they move forward to commercialize the concept or rejected it. The text boxes are stages composed of input-task-event-output. Text boxes with dotted lines are not stages. They do not have all four-stage elements. For example, '*inspection*' is a kind of decision. There is no input and output. The vertical arrows indicate the progress of the flow. It also shows the direction of information flow, where the output of the former stage becomes the input of the next stage. The horizontal arrows show the direction of '*information flow*' or '*interaction*.' The circular arrows represent repeated and strong interaction within the phases. Colours in Figures 3 and 5 show their connectivity. These are later categorized as phases and explained in the next section.

1.2.3 Simplifying the processes

Once we formulated each company's collaborative product design processes, we categorized them to determine the types, purposes, and conditions of them. Yet, as each company's processes include detailed design actions and information, it is not easy to compare them directly between companies. Thus, we simplified each company's design processes with the concept of '*process chunks*' to aid their comparability, while maintaining the essential characteristics.

We found that there was a pattern in a group of small sequential stages. There is a major job completed going through all sequential stages. After completing it, a clear new phase starts with another job. We defined those small stages as '*process chunks*.' It is characterized by initial input, internal iteration, decision-making, final outcome, and irreversible tendency (Figure 4). The internal

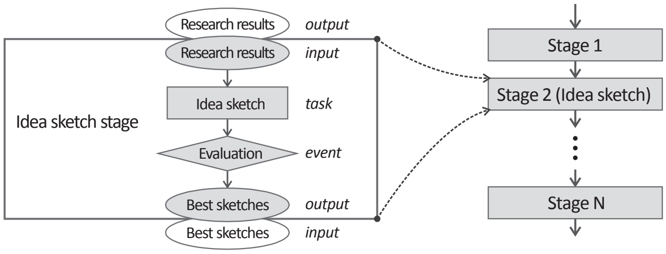

Figure 2 Defining stages

process in a process chunk starts with the initial input and runs across small stages inside. Iteration or feedback can happen among small stages inside the chunk. Finally, they make the final decision about the final outcomes. This is a milestone indicating that the phase is to jump over to the next phase. For example, in Figure 3 in the blue block, the major job in this chunk is to develop a design concept executing six small stages. When they are in the rendering stage, they can go back in the idea sketch stage if the rendering outcomes are not satisfied at the rendering evaluation event. At the last stage, a design mock-up as the outcome is confirmed by a top management, and then it jumps to 'product planning meeting.'

The process flow between the two process chunks has a little chance to be reversed after the previous outcome goes into the input of the next chunk. The cross-teams generally make the final design, which is approved by the top manager at each chunk. To go back to the previous chunk means that it could not meet the timeline to the market. Thus, there should be a top management's decision on the issue. Based on interview data, they would rather drop the project than go back to the previous phase. Iteration and feedback among phases are characterized in most stage-based models (Wynn & Clarkson, 2005). Considering a process chunk or two parallel chunks as a phase in this study, however, the reverse iteration or feedback between phases seldom happens in actual situations. It happens between stages inside a chunk. Thus, it seems that the abandonment of a project is almost impossible between stages but possible between phases.

We named the process chunks by their main jobs. While naming the chunks, we found that the term 'concept design' is used differently by engineering design and industrial design. Concept design in engineering design is about technical concepts related to how a product works by developing broad solutions to the working structure and functions (Haik & Shahin, 2010; Kroll, Condoor, & Jansson, 2001; Ullman, 2009). However, industrial designers decide the direction of product style and interaction at the concept design phase, which is represented with concept keywords, mood boards, idea sketches and user scenarios (Press & Cooper, 2003; Tovey & Harris, 1999; Vredenburg, Isensee, Righi, & Design, 2001). Thus, we marked the concept

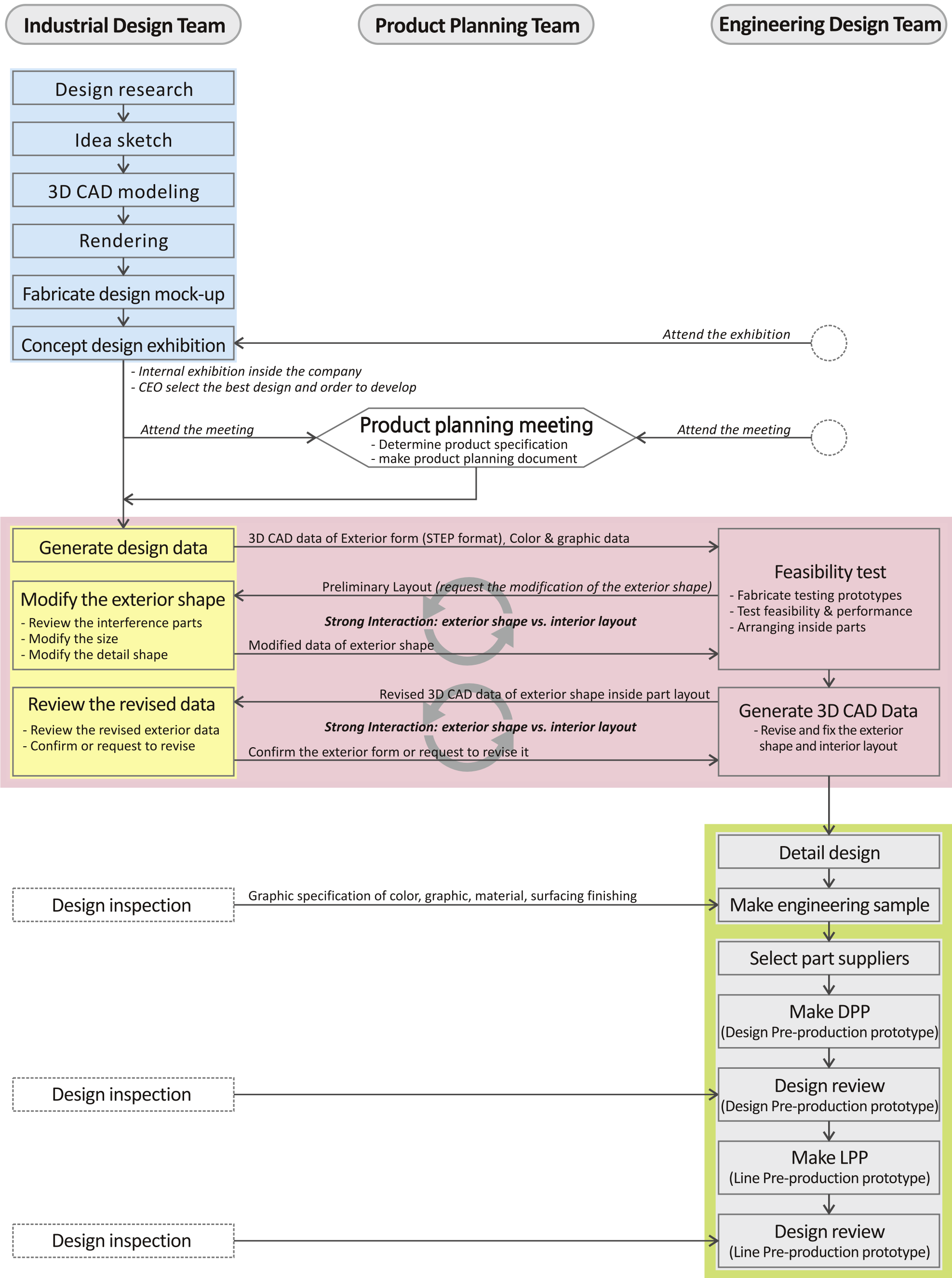

Figure 3 A collaborative product design process of Company A

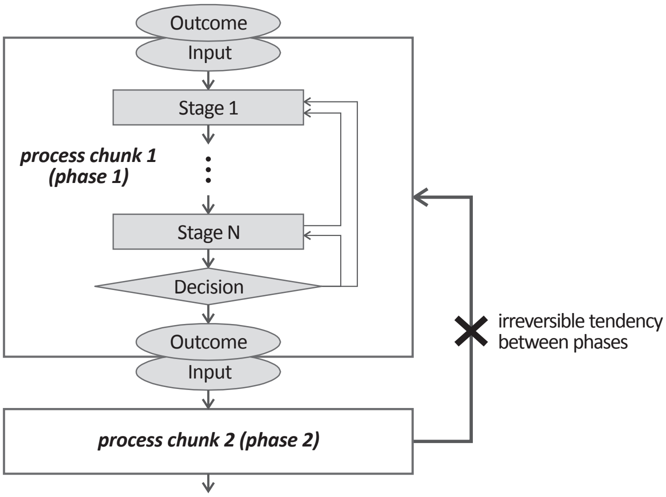

Figure 4 Characteristics of process chunks, and phases

design activity of industrial designers as '*Concept Design-I*' and that of engineering designers as '*Concept Design-E*.'

Figure 5 is the simplified version of Figure 3. The coloured boxes in Figure 3 are simplified with the same coloured blocks in Figure 5. The blue block in Figure 3 becomes '*Concept Design-I*.' 'Product Planning Meeting' in Figure 3 is defined as '*Product Planning*' and visualized with an elongated hexagon. It is determined as a single phase as it is a separated and distinctive design activity. Inside the red block, there are two parallel process chunks; '*Concept Design-E*' on right side (the small red box), that is the '*main process chunk*,' and '*Shape Modification*' on the left-hand side (yellow), a '*corresponding chunk*.' These two chunks are not deemed separate phases because they are coupled with the start to the end inside the big red block. As such, interaction between the two designer groups is strong. To differentiate two parallel chunks, we represented the main chunk with thick solid lines and the corresponding chunk with light solid lines. In the green blocks, as there was a little difference in the design activities between all 12 processes, we combined the two sequential process chunks of detail design and testing and production into one. As such, we treated them as a single phase in this study. When the design process in the green block proceeds, industrial designers react from time to time based on engineering designers' requests or their own purpose for design inspection. They usually called these activities as '*Follow-up*' differentiating from their major tasks. These kinds of activities apparently existed but do not belong to a process chunk. They are discrete process elements as shown in Figure 3, and thus represented with dotted lines. To help visual understanding, solid arrows, a double directional wide arrow, and a single directional wide arrow represent process flow, mutual interaction, and one-way interaction respectively.

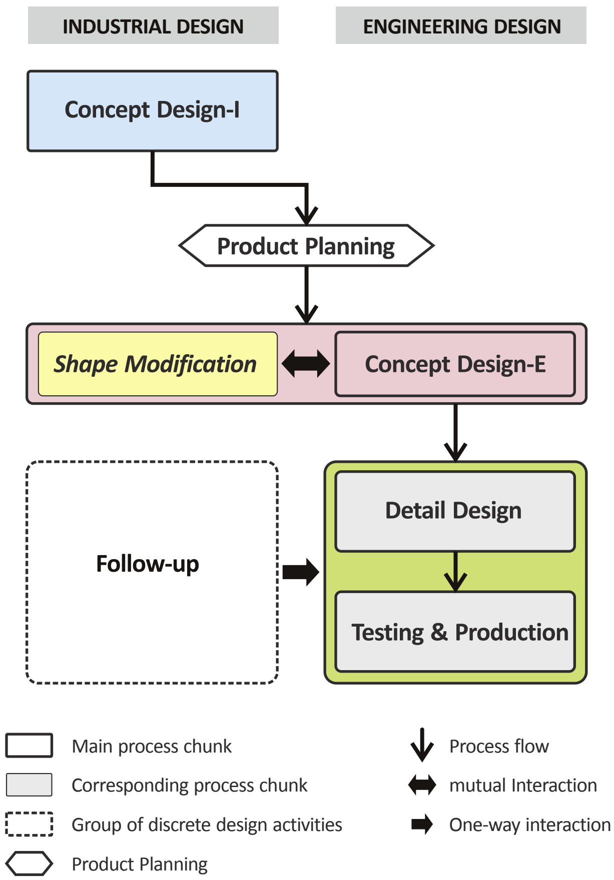

Figure 5 An example of a process model converted from Figure 3

1.2.4 Determining types of collaborative design processes

We compared and categorized the 12 simplified collaborative product design processes based on similarities in their process structure, input and outcomes of process chunks and phases, and interaction between industrial designers and engineering designers. We first compared every process chunk and phase with corresponding process chunks and phases from the other 11 processes in terms of structure. Then, we compared inputs and outcomes of every corresponding phase across the 12 processes. For example, the '*Concept Design-I*' phase in Figure 5 has no input, but produces '*design mock-up*' as an output. Some '*Concept Design-I*' phases in other processes started with the receipt of the preliminary layout from the engineering design teams. Therefore, examining the types of inputs and outcomes of phases give a clue to determine how the overall process flows. Finally, we evaluated the interaction between industrial designers and engineering designers within a phase. There is no interaction between the two groups in the blue block. However, in the red blocks, there are strong interactions between them. As a result, we grouped the 12 collaborative product design processes into four types of representative processes.

2 Types of collaborative product design processes

We named the four types of collaborative product design processes based on their characteristics. They are Type 1: ID-led Concept-driven Process; Type 2: ID-led Combined Outside-inside Process; Type 3: ED-led Inside-first Process; and Type 4: ID&ED Synergetic Process, and differences between them are mostly found in the early phases of the processes where design concepts and preliminary layouts are developed. There is a little difference after the detail design phase where the engineering designers' tasks dominate. It is rather standardized. This indicated that the types of collaborative product design processes are determined by the approaches adopted before the detail design phase.

The companies adopted one to three types of design processes according to their goals and situations (See Table 3). Type 1 and 4 were used only for new designs except Company C which adopted Type 1 when the market requested a new styling within a short period of time. This happened when they had many reference products and lead-time was short. Type 2 was used for both new design and redesign. Interestingly, Type 3 was utilized only for redesign. Most processes were used for B2C except in Company C, 'a mobile communication product manufacturer,' which releases its products to the market through service providers. Considering that, Company C used Type 1 in a different situation from Company A and E, the business type (B2B or B2C) would affect the choice of design processes.

Regarding the difference between actual design process and documented process, most of them responded that they have documented standard design processes in all companies, but they do not follow at all. This is supported by the finding by Maffin (1998) that designers develop their own approaches in accordance with product development context. It seemed that the documented process defined standardized task flows and stages, tasks and roles of each department, and project time according to project types. However, they were always pushed to shorten the actual project time. This kind of management pressure likely causes them not to follow the documented process.

By comparing the frequency of use of each type of process, we found that Type 3 was the most frequently used, whereas Type 4 was the least. Type 2 was used more frequently than Type 1. Except in the case of Company B, Type 3 is most similar to that most interviewees described as the company standard. Considering the argument that redesign occurs more frequently than new design (Roozenburg & Eekels, 1995) and successful radical innovation happens perhaps once every 5–10 years (Norman & Verganti, 2014), this is a reasonable finding. As Type 4 is spontaneously initiated by individuals, and is not a set of official, standard procedures, the case is rare.

Table 3 Four types of collaborative product design processes

Company	*Type 1: ID-led Concept-driven Process*	*Type 2: ID-led Combined Outside-inside Process*	*Type 3: ED-led Inside-first Process*	*Type 4: ID&ED Synergetic Process*
A	●		●	●
B		●		
C	●		●	
D			●	●
E	●	●	●	
F			●	
Goal and Situation	New concept or when market changes fast, many reference products exist and lead-time is short	New concept or re-design	Re-design when clear target market exists	New concept, spontaneously developed process by individual endeavours
	B2C: Company A & E B2B: Company C	All B2C	B2C: Company A, D, E & F B2B: Company C	All B2C

The detailed characteristics of each type of design process along with related contexts are described in the following sections.

2.1 Type 1: ID-led Concept-driven Process

Industrial designers play a dominant role in deciding the direction of product development in the initial stage in Type 1. It has four phases in accordance with the process chunks, as shown in Figure 6.

1st phase (Concept Design-I): Industrial designers independently develop the concept of a product without any interference from other departments. They focus mostly on the aspects relevant to the aesthetic exterior and user experience. They rarely consider the internal parts, which gives a lot of freedom to them. They produce 3D CAD data for the exterior and high-quality rendered images to test the concept. Once the exterior form is finally decided, they produce a '*design mock-up*,' a non-functional prototype, to verify the concept. Finally, the best design is selected at a '*design evaluation meeting*.' The final outcomes in this phase are the 3D CAD data of outer shape and a design mock-up. Engineering designers do not take any action in this phase. Mostly, they are not even aware of what the industrial designers are designing.

2nd phase (Product Planning): The product planning department decides on the commercialization of the selected design as well as on the target market, target price and material cost of the design. Finally, they prepare a product-planning document and establish a specific direction for commercialization of the design.

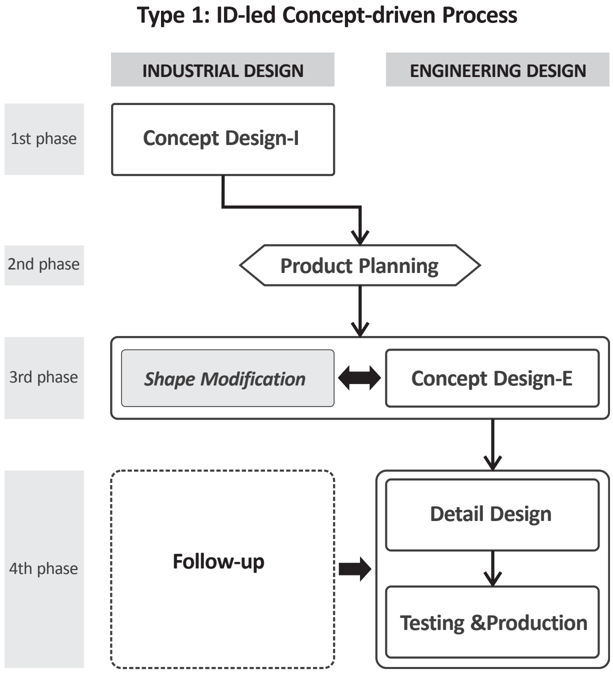

Figure 6 Visual model of Type 1: ID-led Concept-driven Process

3rd phase (Concept Design-E/*Shape Modification*): The product planning document from the previous phase and the final 3D CAD data developed by industrial designers are the initial inputs given to the engineering designers. Engineering designers review the feasibility of the design concept proposed by the industrial designers due to which engineering designers gather relevant technologies and arrange inner parts in the 3D CAD data to test if all indispensable internal functional parts can be fixed inside the exterior form. Sometimes, engineering designers produce experimental prototypes to test if the desired performance can be implemented with the pre-set exterior form. As industrial designers did not consider the internal parts in defining the exterior form, engineering designers have trouble in arranging the inner parts within the given form. Thus, modifying the exterior form is somehow unavoidable. Therefore, there is a corresponding process to Concept Design-E: '*Shape Modification*' by industrial designers. Industrial designers use the layout data received from engineering designers to modify the exterior form. At this point, two goals collide with each other. Industrial designers try to maintain the original form, while engineering designers demand the modification to ensure functionality and performance. In this process, a very close interaction takes place. The outcome is 3D CAD data about the exterior form and interior part layout.

4th phase (Detail design • testing & production/*Follow-up*): From this phase, engineering designers lead the process in all parts. Engineering designers decide on individual parts' geometry and compositional structure based on the 3D CAD data determined at the previous phase. Due to the consideration of mass production or reliability testing, they sometimes ask industrial designers to make minor modifications of the exterior design. Upon completion of the detailed design, working prototypes called '*engineering samples*' are produced to check the form and functionality. At this point, industrial designers evaluate to what extent the exterior form has been produced in compliance with their design concept. Then, engineering designers decide on suppliers, produce moulds, and test '*pre-production prototypes*' through multiple event processes to improve the reliability of performance and the durability of the product.

On the other side, in '*Follow-up*,' industrial designers decide on how to apply colour, graphics, material, and surface finishing to the product and provide relevant specifications for engineering designers. For each working prototype produced, industrial designers test the aesthetic and emotional quality with the specifications. When they give their approval, their official role in the design process ends. Unless they give an approval, engineering designers should produce and test the parts in a question again. We found that all six companies have this mechanism for maintaining the design quality of products.

Type 1 is opposed to the conventional belief that a new product development process starts by identifying market needs via market research, or by developing new technology. It starts with pure industrial designers' conceptualization with full freedom. This implies that new products can be developed based on pictures that industrial designers envision in their minds. This is inconsistent with product design processes described in the engineering design discipline (e.g. in Dym, 1994; Haik & Shahin, 2010; Pahl et al., 2007), where industrial designers' roles in concept design are missing.

Considering the related theories which suggest that creativity happens before the thorough analysis of the problems in a solution-oriented approach (Wynn & Clarkson, 2005), such as '*primary generators*' (Darke, 1979), and the conjecture-analysis model (Hillier, Musgrove, & O'Sullivan, 1972), and other related findings and argument from Lawson (2006) and March (1984), that would be best strategies for a company to give industrial designers freedom and autonomy in generating creative solution concepts without external interference. In fact, Type 1 is employed in two situations: one is to develop new concept products in both shape and function, including the development of new product categories (as in Companies A and E), and the other is to launch a new model of an existing product as quickly as possible (as in Company C). The latter case appears to be possible when there are abundant reference designs so that industrial designers are able to decide on product sizes and exterior elements without any product specification when the lead-time is short.

2.2 *Type 2: ID-led Combined Outside-inside Process*

The companies use this process to develop new types of products or modify existing ones. In either case, unlike in Type 1, the product planning team starts the process. We can explain Type 2 in four phases as shown in Figure 7.

1st phase (Product Planning): The product planning team creates a product planning document to initiate a product development. It sets up a target market, target price, and product specification. When developing a modified version of existing products, it decides on them in line with the existing products, including those of competitors. When developing a new product, engineering designers help decide on them. The outcome of this phase is a product planning document.

2nd phase (Concept Design-I): Upon receiving the product planning document from the product planning department, industrial designers decide on the product's exterior and related interior. They collect functional items needed for the product being developed in compliance with the product size and specification, and also derive form concepts from research on users or design trends. Then, they arrange the interior parts to decide on the exterior form while avoiding any collision between the interior parts and the intended exterior form. Thus, they go back and forth between the outer shape design and the arrangement of the inside parts. There was a little interaction between industrial designers and engineering designers in this phase. For the final event, design evaluation proceeds with non-functional design mock-ups. Thus, the outcome in this phase is the 3D CAD data concerning the exterior form and the initial interior layout of the product, and a design mock-up.

3rd phase (Concept Design-E/*Shape Modification*): Upon receiving the 3D CAD data from industrial designers, engineering designers closely inspect the feasibility and operability of the interior parts in connection with the exterior form and develop the final layout. While engineering designers check them, and frequently request industrial designers to modify the layout or the outside form. Thus, industrial design activities proceed with a corresponding process; '*Shape Modification*.' However, the form change is not as significant as in Type1 because they decided the exterior form in connection with the interior parts in the previous phase. The outcome in this phase is the 3D CAD data about the final exterior form and the definitive layout of the interior parts.

4th phase (Detail design • testing & production/*Follow-up*): This phase is not significantly different from that in Type 1.

A notable characteristic of Type 2 is industrial designers' active involvement in arranging inner functional components while deciding the outer shape in the 2nd phase. Although industrial designers' knowledge of the linkage between interior layout and the outer shape is less engineering-focused, this case clearly

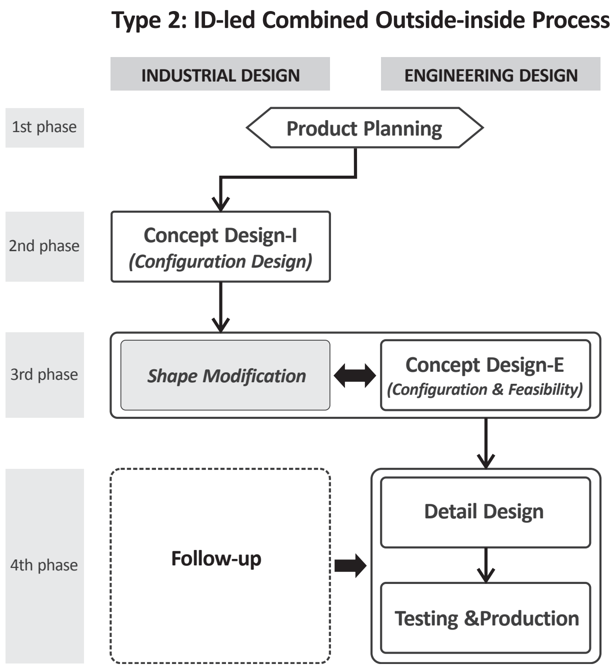

Figure 7 Visual model of Type 2: ID-led Combined Outside-inside Process

demonstrates that the role of industrial designers has extended beyond what we normally expect. As a result, the industrial designers become influential and take the initiative in decision-making. In addition, engineering designers are hardly involved in this phase. We expected that layout design would be an exclusive job of engineering designers, as suggested by the engineering design literature (e.g. Hubka & Eder, 1987; Pahl et al., 2007; Ullman, 2009). We assumed that at least engineering designers would actively provide advice and guidance for industrial designers. However, they expected the data to arrive from industrial designers and granted industrial designers freedom to complete outside form in connection with the inside structure of a product. The design-first policy of the company seems to be the main reason at this point.

2.3 Type 3: ED-led Inside-first Process

Type 3 is different from Type 1 and Type 2 in two points: they use it only to redesign the existing products, and engineering designers' activities proceed prior to industrial designers. It requires a more prominent role for engineering designers while reducing the role of the industrial designers. We explain their characteristics as follows:

1st phase (Product Planning): As shown in Figure 8, the product planning team firstly initiates the product development project based on the annual roadmap of product development. At this point, they do have a functional concept of the products in the roadmap. Product planning experts determine the target market, target price, product size, and material costs based on the existing products in the market. Frequently engineering designers help them develop the product specification by analysing technical parts of competitors' products and estimating the material cost. The outcome of this phase is the product-planning document, which includes product specification.

2nd phase (Concept Design-E): Engineering designers rapidly develop a preliminary layout based on the product specification. They commonly use the data of previously developed products. Upon its completion, they send the preliminary layout as 3D CAD data to industrial designers. This is the starting point of industrial design process. Industrial designers use it as an input to develop the exterior form, while engineering designers seek solutions for system performance and continue to refine the layout. As the interior layout and the exterior form develop simultaneously, both teams closely interact and discuss any points of disagreement or conflict, and repeatedly exchange feedback for modification. Eventually, the preliminary layout becomes the definitive layout while the design sketch develops into the definitive exterior form. The outcome in this phase is the definitive layout reflecting the final size of the product being designed.

2.5th phase (Concept Design-I): This process is far from an independent subsequent phase but rather an intermediary phase between the second and the third. Thus, we shall call it the 2.5th phase. It starts upon the receipt of preliminary layout from engineering designers and progresses concurrently with Concept Design-E. The industrial designers check the interior layout and overlay with a matching exterior form. They undertake idea sketches, 3D CAD modelling, rendering, design evaluation meetings, and a mock-up selection event to decide on the exterior form design. Engineering designers keep advising and evaluating on the exterior form. As such, the exterior form and layout develop little by little through the intertwined Concept Design-I and Concept Design-E.

3rd phase (Detail design • testing and production/*Follow-up*): This phase is not markedly different from that in Type 1 and Type 2.

All companies except Company B used this process. This indicates that it is most widely used. Interviewees noted that this process is comparable to the companies' official guidelines for design processes in terms of roles, tasks, and stages. However, they mentioned that the actual period is shorter than that specified in the guidelines.

2.4 Type 4: ID&ED Synergetic Process

Type 4 took place not by official proposal but individual designers' efforts in the early phases. In many cases, engineering designers involved in developing

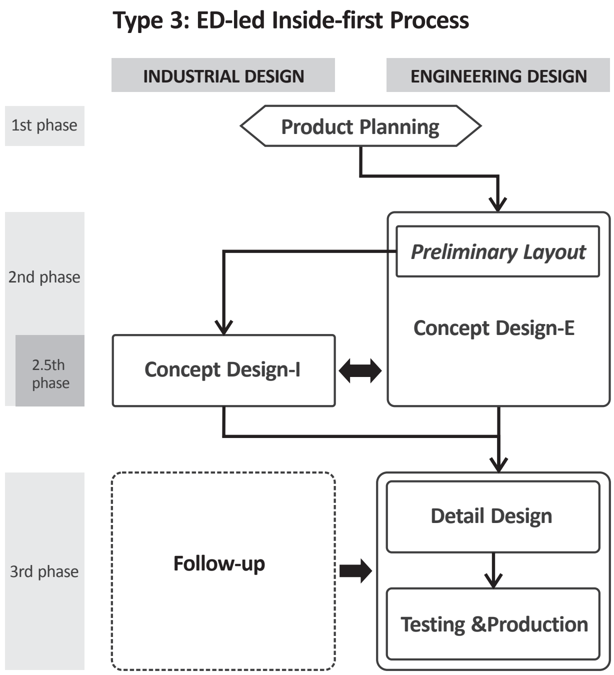

Figure 8 Visual model of Type 3: ED-led Inside-first Process

line-up models tend to reject novel design concepts proposed by industrial designers, because of feasibility issues within the limited time. To implement the concepts, industrial designers work with engineering designers who are freer. Therefore, this process makes it possible to continue with novel design concepts that were rejected. In addition, industrial designers and engineering designers make synergic efforts. Breaking away from the conventional separated approach, they handle a design concept in an integrated way considering many design variables concurrently. The detailed phases of this process are as follows):

1st phase (Concept Incubation): As in Figure 9, industrial designers conceive of a new design independently. They mostly build it from the design ideas that were excluded from proceeding projects despite their innovativeness.

2nd phase (Concept Design): This phase starts when industrial designers seek engineering designers who can work with them. When an engineering designer agrees to join the industrial designer for implementing the design concept, they work closely throughout this phase. The engineering designer provides state-of-the-art technology for the industrial designer to sharpen the design concept. The first level of inside layout is developed based on the outer shape that is being developed. The outcomes of this phase are the 3D CAD data about the exterior form and interior layout.

3rd phase (Product Planning): Product planning team decides commercialization of the design via a design evaluation meeting. Then, the product planning team defines the target market for the design. From this phase, the engineering designers in charge of developing line-up models become involved.

4th phase (Detail design • testing & production/*Follow-up*): The process of this phase is not much different from that in Types 1, 2, and 3.

The existing product development environment causes engineering designers to be conservative. Most development projects in the domain of consumer electronics are urgent. Companies usually set a product launch day in their plans. Thus, designers execute all tasks and events following the timeline to the day. Based on the interview data, engineering designers involved in these kinds of projects tend to reject novel design concepts proposed by industrial designers, because they feel that they could not ensure their work with the concepts pass the performance and reliability tests by the chosen time. The failure of the testing will directly influence the company's product development roadmap as well as the engineering designer's annual performance when evaluated. This seems to make them select and evaluate design concepts conservatively. Therefore, this process is hardly available to the designers who are directly involved in projects proceeding on a timeline to the market. Conversely, engineering designers who are relatively free from the timeline to the market, for example, those involved in developing advanced technology for future products will be more open to novel design concepts. Besides, more importantly it seems that designers who are more open-minded to collaborative works with other experts tend to execute this process.

In the case of Company D, Type 4 had a great market success with a new product by employing this process. However, further cases actively applying this process to following projects were not reported in our interview. Nonetheless, it is interesting that Company D dispatched several engineering designers from the advanced technology development team to a neighbouring office of the industrial design team. This enabled the synergetic process case. The top management purposely moved them to prevent industrial designers producing unrealistic design concepts by letting them provide necessary technical supports promptly for industrial designers. This seems to stimulate both parties to be more intimate, thereby creating a cooperative mood. This will increase the possibility of emerging integrated design processes.

3 Discussion and implication

3.1 Role change

Industrial designers' contribution is dominant in the concept design phase and afterward, engineering designers take over their major role. This can be

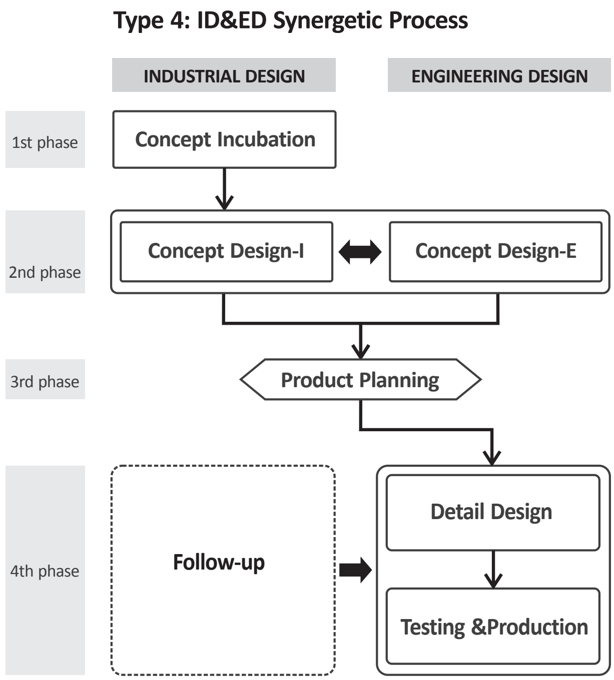

Figure 9 Visual model of Type 4: ID&ED Synergetic Process

regarded as the general characteristics of the four types of design processes. With the exception of Type 3, all the design processes started with design concepts developed by industrial designers. In the case of Type 1 and Type 2, industrial designers independently define the design concept in terms of shape and use. Type 4 is integrative in the concept design phase, but starts with the industrial designer's initial design concept. Unlike the other three types, Type 3 cases, where the scheduled modification of existing products happens, start with the layout design by engineering designers. It appears that their roles are divided as concept developers and concept implementers. Interestingly, as a company pursues new concept products or emphasizes emotional feeling and usability even in re-design cases, the role of industrial designers seems to be significant. This is a different phenomenon from the idea that a new concept product is developed through the development of new principles and technology. They rather devised new uses or the meaning of existing ones. Therefore, this can be viewed as evidence that new design also starts with existing technologies and principles.

Regarding industrial designers' knowledge, counter to our belief that they would rarely consider inside parts, they seem to have enough knowledge to read and handle the inside functional components and carry out the outside design. Except for Type 1, defining the outside shape always happens through considering and rearranging the inside functional parts by industrial designers. Type 2 is an unexpected case. Industrial designers develop the outer shape by arranging the related inside components at the same time. However, their work on the inside parts was probably limited to major parts that directly affect the outside shape. Although, they were not fully involved in designing the details of inside parts, it is apparent that their role was extended to the area of engineering design. It is attributed to the top management's strong support to industrial design and the shared CAD tools between both groups.

3.2 Selection of design approach

Theoretically 'inside-out' and 'outside-in' approaches happen and are caused by the combination of different working tendencies of engineering designers and industrial designers (Hubka & Eder, 2012; Kim & Lee, 2010). The four types of collaborative design processes can be seen as extended versions of the two approaches. This section discusses the relationship between the four types and the two approaches, conditions for applying each type successfully, and applying them in consultant and client partnership settings.

For consumer products whose contexts of use are emphasized, industrial designers are supposed to firstly define the exterior in relation to usability and appearance, and then engineering designers decide the interior functional parts linked with the exterior to support the usability and appearance. This is an outside-in approach where Type 1 is suitable and Type 2 is nearly appropriate in such contexts. If we define inside-out process as deciding preliminary layout first and then using it for developing the ensuing outside form and definitive layout together, Type 3 is a case. Considering the two approaches, Type 4 is considered as a mixed process, because both exterior and interior are defined simultaneously. If we define inside-out process as deciding the exterior after completing interior definitive layout, there is no such process across the companies studied here. It is less suitable for use with consumer products. It is rather suitable for industrial durable goods. For example, if we design an industrial motor, the capacity determines the winding number of electric wires and the size of magnetic cores. We should calculate the layouts and sizes of interior rotors and stators scientifically to achieve optimal performance. Thus, the interior parts must be fully decided first, and then the exterior form is defined to overlay. If we develop the interior parts of a motor based on a pre-set exterior form, it will not operate properly.

When using Type 1, industrial designers can come up with innovative design ideas freely. Nevertheless, the approach will lead to two problems. First, it will be difficult to gain technological performance in engineering. To achieve optimal performance, the internal functional parts may clash with the exterior shape. Second, to solve the first problem the design team is likely to compromise the original design concept through trading off between functions and appearance. To manage this approach successfully, top management's strong support to keep the innovativeness of the design will be necessary when a compromise is to take place. Type 2 could be an alternative solution to the problems as we observed in Company B. Its strategy was that industrial designers decide the exterior form while moving or placing the related interior parts. This avoids critical interference between exterior and interior parts. Yet, it is arguable whether industrial designers should execute the interior layout design in addition to the exterior form development at the expense of the freedom of imagination. It is probable that they compromise innovativeness within their knowledge. To apply Type 2 successfully, designers should be highly knowledgeable about both industrial design and engineering design.

To attain the feasibility of a superior design concept in the early phase, Type 4 is worth noting as industrial designers' concepts and engineering designers' technical support enable new product development. Given this process is efficient and likely to develop innovative products, companies need for it proper conditions to employ. Dyson Company can be a role model. It is known that designers and engineers share a workspace as members of a department for the integrated implementation of design (Dyson & Coren, 1997). To facilitate this process, companies need to have an integrated team where two groups share a working space and absorb each discipline's culture as expected. More important is the organizational culture that stimulates designers to be challenging and open to work together. If designers are worried about company's penalty for a failure, they will be more conservative. Without this situational change, Type 4 even as a well-documented process in a company will not effectively work.

In industry, many engineering companies collaborate with external industrial designers. Although, we did not investigate this type of collaboration, discussion about possible process scenarios in reference to our findings will be beneficial. When manufacturers work with design consulting firms, they can receive complementary support to complete the project on time or generate fresh ideas (Bruce & Morris, 1994). In consultant and client partnerships, there are two modes of process couplings: passive coupling where consultants develop solutions independently while they contact the client to get additional information or review their outcomes, and active coupling where the collaborative team of consultants and clients designers work closely to generate solution (Gericke & Maier, 2011). In passive coupling, as the external designers work independently, its design process will be similar to Type 1 or 2. Type 1 will be useful when clients want to collect creative ideas as many as possible by utilizing the specific specialities they missing. This case will be helpful when client companies are highly technology-oriented and have enough capability to implement good concepts with strong engineering supports. Type 2 will be appropriate when clients have less capability than in the above-mentioned case and are required to utilize external industrial designers to lead their product development at the initial stage. The active coupling mode will have similar processes to Type 3 and 4. Type 3 will be appropriate when clients already have good design direction and related technology, and want to improve the aesthetic appearance of the product. Type 4 will be reasonably impossible unless the integrated team of client and consultant companies work in the same space during project time. There should be other factors to consider in collaborative design processes in consultant and client partnership. In many cases, information provided by clients for consultants is restricted to some extent. Therefore, the same types of collaborative processes happening in a consultant and client partnership and inside of a company will not be the same in terms of contents. Nevertheless, our research results and discussion could provide clues for selecting a better design approach in the consumer electronics domain.

3.3 Implication of the types of design processes

Industrial designers and engineering designers are different in their design approaches, and perspectives about product development (Eder, 2013; Pahl et al., 2007; Ulrich & Eppinger, 2012). Industrial designers generate user-centred solution concepts, and engineering designers solve design problems based on technical perspectives. The process exposed to these two groups' specialities can be the basis for developing competitive and innovative products. Moreover, the coupling process of systematic engineering design and user-centred design thinking is beneficial for generating user-centred solutions in consultant–client relationships (Gericke & Maier, 2011). The coupling process is the best option for a company to take, and achieve competitiveness in the market. For example, consumer electronics companies use the four types of collaborative design processes to achieve their market goals. Industrial designers' role in the early phase of the four types is noticeable and the way of adopting industrial designers' specialities is an influential factor in adopting an appropriate type of collaborative design process. The possibility of obtaining innovative design concepts can be increased by giving freedom to industrial designers as in Type 1. Then, how can such freedom drive industrial designers to create innovative design concepts? In fact, architectural and industrial designers start with the solution image firstly and finalize by following repetitive trials (Lawson, 2006; Roozenburg & Cross, 1991). This is consistent with a model where designers firstly engage in conjecture based on presuppositions and then perform analysis (Hillier et al., 1972). It implies that industrial designers rely on envisioning the future to create innovative concepts rather than thick design research about market and customers. Press and Cooper (2003) added that industrial design approach is value-driven. Therefore, industrial designers in Type 1 are given freedom from constraints to generate creative ideas through envisioning the desired future.

Norman and Verganti (2014) argued that innovative product development takes place with technology or meaning change rather than serious design research with human-centred approach. They added that human-centred design methods are more suitable for the incremental improvement of existing products. In the current product development environment in the consumer electronics domain, product-planning experts play a pivotal role in research on market and customers. Thus, the input from the product planning team to industrial designers will be restricted to their creativity. This explains why companies utilize Type 1 in a reverse way; developing concepts first and then defining the market next rather than the other way around. Typically in product design concept, designers consider function concept that is highly related to technology, and styling concepts that give new meaning to the users (Baxter, 1995). Thus, the design concept produced by industrial designers should be innovative, because of the function and/or styling concepts. When it relates to the technology, engineering designers should develop new technologies or search appropriate technologies to implement the concept. This type of process can lead to new technology development if not rejected in the product development planning stage.

In Type 2, the company imposes various roles and responsibilities on industrial designers. As engineering designers do not interrupt, they may have a certain level of freedom. Industrial designers' approach is solution-oriented. They do not usually follow systematic process. They rather come up with new ideas and repeated them. However, Type 2 probably interrupts industrial designers approach by imposing another role in which they handle inside layout design with the exterior design. Industrial designers adopting problem oriented and systematic approaches will definitely restrict them from imagination in concept development. This will make them more realistic when considering the feasibility of their design concepts. As such, the design outcome of Type 2 will be less innovative than that of Type 1. Otherwise, Type 2 will be better fit for redesign than new design. If industrial designers do not consider the inside parts in Type 2 for redesign, they can face difficulties, and the design concept can be rejected (Kim & Lee, 2014).

If we consider applying Type 2 and Type 3 for redesign, when does Type 2 better than Type 3? The characteristics of Type 3 are in accordance with most design processes shown in engineering design. Industrial design has been considered as an afterthought in the engineering design field (e.g. Andreasen & Hein, 2000; Hubka & Eder, 1987; Pahl et al., 2007). As per their viewpoints, industrial design's function is related to the aspects of product appearance, such as styling, form and colour after a product's technical features are determined. Type 3 is the process where engineering designers have technological solutions to the design concept. They request industrial designers to develop exterior appearance. Thus, Type 3 uses only part of industrial designers' expertise in creating aesthetic appearance. In this perspective, Type 2 can offer more ways for industrial designers to show their expertise than Type 3. Considering the fact that Type 3 is the most frequently used process, it can be more efficient in terms of process management. Probably, the uncertainty in the early phase in Type 3 is the least among the four types. Most of the technical solutions for the design concept are set by engineering designers in the early phase, and industrial designers are only limited to create aesthetic appearance.

The one process we could not discover would be Type 5: ED-led Technology-driven process. This could be contrasted to Type 1: ID-led Concept-driven Process. In Type 5, engineering designers would develop a new technology at first without consideration product development plan, and test its performance with testing prototypes. Next, industrial designers generate new product design concepts for the technology. Then, the visualized design concepts and the prototypes could be used to decide product development. Applying Type 5, a company could create a new category product that increases the possibility to open a new market. One of the reasons that we could not find this type would be the rareness of innovative technology development, and a rare chance for new technology to meet a new concept. In addition, a company is unlikely to wait for engineering designers and industrial designers with great uncertainty until the product development is decided. To make this process better, we need engineering designers to develop new technologies, and industrial designers to create new concepts using technology with mutual cooperation. From this argument, Type 4 can be useful in applying officially for innovative product design. It can also enable the technology developed by engineering designers to be integrated with new concepts generated by industrial designers.

4 Conclusion

We aimed to determine the existence of the types of collaborative design processes, and the conditions of adopting a particular type in a company. We established collaborative design processes from in-depth interview data of industrial designers and engineering designers. As a result, we found four types of collaborative design processes. They were categorized according to the difference of the early phases of the design process. The four types of processes are used for different purposes in different contexts. At times, they are applied strategically to develop new design or redesign, and at other times they are applied organically due to internal and external forces. We also found that the role of industrial designers is influential and extended.

The abstract character of design process models and the mono-disciplinary approaches in research are not well-matched to actual practice and are identified as the causes of this problematic situation (Brooks Jr, 2010; Eckert & Clarkson, 2005). In this regard, there has been a request to combine different design process models (Albers, 2010; Dorst, 2008). The four types of processes are combined processes of a solution-oriented approach driven by industrial designers and a problem-oriented approach by engineering designers. They show the actual design process is not represented with a single model even in a single domain, i.e. consumer electronics. To improve the applicability of design processes and to receive the suitable support of design methodologies in design practice, more concrete process models that consider the specific context of a company and project are needed (Finkelstein & Finkelstein, 1983; Gericke & Blessing, 2011). We specifically focused on the consumer electronics domain where industrial designers and engineering designers importantly collaborate in product development. We found the four types of design processes and identified their purposes and contexts. Thus, our findings with the contextual detail will provide useful information for companies planning efficient design process management for new product development, especially in the consumer electronics domain.

In light of the research methodology, we have shown how collaborative design processes can be established from in-depth interview data of designers. We identified process elements, constructed partial processes with them, and built detailed collaborative design processes with our mosaic method. We also introduced 'process chunk' and defined a chunk or two interacting chunks as a phase. We argue that this approach is beneficial to determine actual design process at best level. We think this method is applicable to the discovery of other design processes. The form of our process models is comparable to other phase-based models (e.g. French, 1998; Pahl et al., 2007). We found from our models that reverse iteration or feedback rarely happens between phases. This is different from the description of existing phase-based engineering design process models. In an ideal situation, we think bidirectional iteration is possible, but practically because of severe market competition, we conclude that it seldom happens.

Further studies with this method are required especially toward other project cases in other product domains. The companies in this study were all manufacturers of electronic products. Therefore, the result is limited to this product category. We need to test how the four collaborative design processes are applied in other companies. Conversely, it is worth studying cases of innovative product development and the processes applied.

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