Examination of Platform and Differentiating Elements in Product Design

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Abstract

The problems of mass customization, portfolio design, and platform design all pose a common challenge to the designer: knowing how to partition a set of product variants to maximize commonality and simultaneously achieve sufficient differentiation for purposes of customization. This research focuses on the particular issue of how differences between platform elements and differentiating elements are evidenced in the product layout or configuration. The premise of this research is that certain architectural properties, such as modularity, vary between platform and differentiating elements. In particular, certain measures of commonality offer an appropriate set of indices for evaluating these differences in a systematic and repeatable manner. Both function and physical solution commonality provide a descriptor with which to distinguish and rank platform and differentiating elements. By evaluating components of a product in terms of function commonality, physical solution commonality, and modularity, a comparison can be made between platforms and differentiating elements with respect to these indices. The hypothesis of this work is that platforms are integrated and the non-common differentiating elements are, relative to the platforms, more modular. While anecdotal evidence exists to support this idea, the purpose of this work is to evaluate two existing product families as a means for analyzing this hypothesized relation. The result of this research is a descriptive set of knowledge that illustrates distinguishing factors between platform and differentiating elements. The data specifically demonstrates the differences in modularity between platforms and differentiating elements, thus suggesting how this design aspect can and should be addressed during design. While not the focus of this study, future research involving a more prescriptive approach to design can directly benefit from the results. The knowledge gained in this work serves as a foundation for addressing portfolio design where both customization and commonality are key issues.

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1. Introduction

Product families, or portfolios, are a set of related products that are generally unique yet common in certain aspects where this commonality is recognized as a product platform. The design of product families is difficult because design solutions should satisfy the needs of different customers while maximizing the commonality among the variant products. This is an inherently conflicting situation yet companies like Sony (Sanderson and Uzumeri, 1997), Volkswagen (Bremmer, 1999), and Black and Decker (Meyer and Lehnerd, 1997) have demonstrated that reductions in cost through commonality can be achieved while increasing product variety. A central thrust of product family and product platform research is the development of theories for explaining how this design task can be managed successfully. Understanding both major and subtle differences between platform and differentiating elements is a fundamental component toward the development of improved theories of portfolio design. This paper represents a new development in portfolio design theory and reports on an examination of a somewhat narrow set of parameters as they relate to the differences between platform and differentiating elements. In this work, we distinguish between unique and common (platform) product features by denoting these groups as differentiating and platform "elements." A basic assumption is that such a distinction is plausible for a great number of parameters that encompass design artifacts (eg. physical assemblies and components) and other resources including for example, manufacturing and supply chain lines. One contribution of this research is the presentation of evidence that illustrates the relationship between commonality and modularity.

Product portfolios are defined in terms of their architecture that can range from a single architecture offering on one extreme, to several completely customized products on the other. Somewhere in between this range lie product families. These are a set of related products that share common features, the family platform, and have selected differences in order to satisfy different segments of the market (Otto and Wood, 2001). Product family design can potentially be addressed at several stages of the design process from customer needs analysis to embodiment design and to some extent during detailed design. For example, researchers have shown how an analysis of customer need distributions can indicate the kind of architecture that is most appropriate (Yu et al., 1999). Note that product architecture generally deals with the layout and configuration of design solutions where such layout has a substantial impact on product family structure. In this work, we specifically focus on product family design at the product architecture design phase. This design stage is selected for two reasons. First, the architecture design phase is an excellent period during which the designer can explore alternative platform configurations and impose product family decisions on the design solutions. Architecture design occurs relatively early in the design process where many configurations are possible without certain restrictions that come with the later stages of embodiment and detailed design. Second, this design stage involves both function and physical solution design aspects that are both leverage points for managing product architecture.

In the context of architecture design, the premise of this work is that architectural distinctions can be made between product platforms and the differentiating elements. That is, elements such as functions or physical solutions can be distinguished as platform or differentiating based on certain characteristics. There is a continuum between common and unique characteristics although platform and differentiating elements in this work are distinguished as being either unique or common with other products in the product family. The hypothesis is that platforms are relatively integrated while unique elements are more modular. In part this hypothesis is based on recent work (Kurtadikar et al., 2004) where product evolution data suggests that platforms are relatively more stable (less variation over time) than their non-common counterparts. This notion of platform stability leads to the speculation that such stability is correlated with more integrated designs. This rationale is sensible because integrated designs have a high degree of internal coupling that is more suitable and consistent with a solution that changes infrequently. By contrast, a frequently changing design would benefit more from a modular architecture that is more flexible to design changes (Rajan et al., 2004). Thus the purpose of this work is to test this hypothesis by examining product families and determining the relation between commonality and modularity.

The remainder of the paper reviews related work and formulates the research problem to clarify deliverables. An experimental analysis section addresses the overall approach and presents details of a case study. Sections for results and discussion provides a direct view of the outcome of the analysis and offer insights to explain our results. Conclusions summarize the main contributions of the work in a context that extends beyond the case study.

2. Related Work

Previous research efforts have addressed the importance of platform design, certain strategies for developing platforms, and several metrics for evaluating the commonality of designs within a family. Highlights of this prior work are briefly summarized below to show current perspectives on platform design and to clarify distinctions between platform and differentiating elements.

Simpson (2004) presents a substantial overview of current product platform design research including a summary of numerous approaches for product family design. A recent effort by Kurtadikar et al., (2004) reports on a customer needs approach for product family design and also presents a review of three categories of portfolio design strategies including i) component based, ii) function based, and iii) managerial/business approaches. Component based approaches are form-centric and offer the advantage of accounting for tangible elements (eg. components and assemblies) of systems. Several evaluation metrics for these physical artifacts have been developed to measure commonality. After its introduction in 1981, the commonality index has been the motivation for at least seven different commonality measures (Collier, 1981; Gonzalez-Zugasti et al., 1998; Kota and Sethuraman, 1998; Martin and Ishii, 1996, 1997; Ortega et al., 1999; Siddique et al., , 1998; Simpson et al., 2001). In an effort to compare and evaluate various commonality metrics, Thevenot and Simpson (2004) analyzed several commonality measures with respect to i) ease of computation, ii) repeatability, and iii) accuracy and found that often the most appropriate measure is dependent on problem constraints such as availability of product data.

One portfolio design technique is to use a scale-based approach where scaling variables are used to "stretch" or "shrink" the product in one or more dimensions to satisfy a variety of market niches (Fujita et al., 1998; Hernandez et al., 2001; Messac et al., 2002; Nayak et al., 2002; Rothwell and Gardiner, 1990; Simpson et al., 2001). This scale-based approach is commonly used in the aircraft (Aboulafia, 2000; Sabbagh, 1996) and automotive (Kobe, 1997; Naughton et al., 1997; Siddique et al., 1998) industry. In general the platform design strategy is to use a common platform across multiple market segments. Meyer and Utterbeck (1993) show that this platform can be interpreted as a core capability where the platform commonality may be sought in several different areas including manufacturing, distribution, in addition to product design. Corbett and Rosen (2004) explicitly note that a "*..platform can be considered as a set of technologies, components, or functions, **and their arrangements** that are utilized for more than one product.*"(emphasis added) This definition is notable because it explicitly captures the notion of topology with the argument that a platform is both a set of items *and* the structure of those items. Clearly there is an intimate relation between architecture and product family design. This paper focuses on this link by examining the modularity attribute of architecture. In other work, the market segmentation grid introduced by Meyer (1997) has been used to identify platform leveraging strategies for computers, data storage systems, power tools, and office furniture (Meyer and Lehnerd, 1997); spacecraft and avionics (Caffrey et al., 2002); and software (Meyer and Lopez, 1995). The market segmentation grid has also been utilized to plan platform-based development of information systems (Meyer and Zack, 1996), non-assembled products (Meyer and Dalal, 2002), and services (Meyer and DeTore, 2001).

Many approaches often use modules for developing commonality in portfolios (Simpson, 2004). This allows for the derivation of product family members by adding, substituting, and/or removing one or more functional modules from the product platform (Allen and Carlson-Skalak, 1998; Baldwin and Clark, 2000; Blackenfelt, 2001; Dahmus et al., 2000; Gonzalez-Zugasti et al., 2000; Martin and Ishii, 2000; O'Grady, 1999; Otto and Wood, 2001; Sanderson and Uzermeri, 1997; Siddique and Rosen, 1999; Stone et al., 1999; Tseng and Jiao, 1998; Ulrich, 1995; Yu et al., 1999; Zamirowski and Otto, 1999). The basic concept of modularity is an attractive feature for portfolio design, whether at a function or form level, due to the compartmentalized nature of modules that promotes flexibility during change whether this change may occur during iterations in a single design project or over a broader period of product redesign and evolution. Many different concepts (Rechtin, 1997; Kusiak, 2002; Gershenson et al., 2003) and measures (Holtta and Salonen, 2003; Guo and Gerchenson, 2003; Gershenson et al., 2004) have been proposed for modularity where recent work by Wang and Antonsson (2004) argue that modularity is "*..an attribute of a system describing the degree of overall coupling between function units..[where]..this coupling may occur at multiple length-scales and dimensions*." This system attribute is a property of system *architecture* and therefore describes the layout and configuration of a system. Again, many samples of prior work have introduced techniques that use modularity in designing both product architecture and product families. Yigit and Allahverdi (2003) develop an optimization method for selecting modules in reconfigurable manufacturing systems. Asan et al. (2004) develop a decomposition and composition based method for developing modular product architectures while Stone et al., (2000a, 2000b) present both heuristic and quantitative techniques for establishing product architecture. Hofer and Halman (2004) introduce the notion of a *layout platform* for accounting for establishing generic subsystem units, which are essentially an abstract type of module. Chandrasekaran et al. (2004) show that a design template concept can be used to manage modules to develop product families. Fujita and Yoshida (2004) develop an optimization method that accounts for both modules and module attributes. Kusiak (2002) addresses the product and the design process from a modularity perspective. Theses approaches demonstrate widespread use of modularity for portfolio design and this paper attempts to clarify how modularity differs between platform and differentiating elements in a descriptive empirical study.

3. Problem Formulation

The techniques reported in prior work provide several *prescriptive* solutions for designing product families; however, a *descriptive* account of the general differences between platform elements and differentiating elements with respect to the modularity attribute of product architecture is incomplete. The importance of a descriptive understanding and explanation of these differences suggests that a careful investigation of these distinctions is needed in order to better judge current techniques and to provide meaningful support for the development future prescriptive efforts. The deliverable of such a study is a theoretical contribution that clarifies certain differences between platform and differentiating elements. Broadly this result is a needed component toward a more complete theory of both platform design and the nature of product architecture. Such a theory should ultimately help answer basic questions about these areas. For example, the use of an agent-based or human-centered approach requires knowledge of what constitutes good design practice for specifying platforms and differentiating elements. What are generally the best candidates for platforms? Given a functional model, which functions are more appropriate for consideration as potential platform elements? We suspect the differences between platforms and variant elements extend beyond commonality differences and we hypothesize that the architectural property of modularity varies between these groups where platform elements are more integral and differentiating elements are more modular. The specific deliverable of this work is evidence that demonstrates the degree to which this hypothesis is true. The end result is heuristic knowledge derived from this evidence.

4. Experimental Analysis

The following detailed examination of a product family is an approach we use to test the research hypothesis of this work and *does not* represent a proposed design method. The purpose of this experimental approach is to simply gather evidence in a case study format to evaluate the hypothesis, and is not intended to be used during the execution of design. However, the evidence gathered by this test is expected to provide a better understanding of the differences between platform and differentiating elements.

4.1 Analysis Approach

In order to test the variations between platforms and differentiating elements, a sample of existing products is used as a case study. For this work, the raw data previously collected by Thevenot (2003) on the Fuji and Kokak families of single use cameras is chosen as a data source. This data consists of comparisons of components of each product variant within their respective family. The Fuji family contains four variants: no flash, flash (old, new), and waterproof. The Kodak family contains seven cameras with specific functions: flash, no flash, digital processing, waterproof, black and white, and APS (Advanced Photo System) with a switchable format. Components are noted as common, variant, or unique among the comparable components in their family. Using this raw data, the current work presents an analysis to evaluate functional commonality, physical commonality, and modularity of individual components. Tables 1 and 2 illustrate the camera families and certain basic features.

Table 1. Fuji camera family (from Thevenot, 2003)

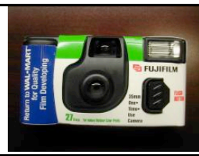
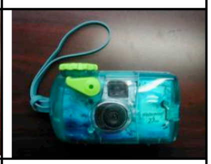
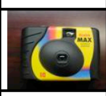
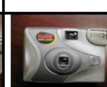
	Quicksnap Outdoor	Quicksnap Flash - old	Quicksnap Flash - new	Quicksnap Waterproof
				
Film	35 mm color	35 mm color	35 mm color	35 mm color
Flash	No	Yes	Yes	No
Waterproof	No	No	No	Yes

Table 2. Kodak camera family (from Thevenot, 2003)

	MAX Outdoor	MAX Flash	Plus Digital	MAX HQ	ADVANTIX Switchable	Black & White	MAX Water & Sport
							
Film	35 mm color	35 mm color	35 mm color	35 mm color	24 mm color	35 mm black and white	35 mm color
Flash	No	Yes	Yes	Yes	Yes	Yes	No
Waterproof	No	No	No	No	No	No	Yes
Switchable format	No	No	No	No	Yes	No	No
Digital Processing	No	No	Yes	No	No	No	No

In order to look beyond the point problem of a case study analysis, the experimental approach should be considered in the context of how results obtained from this study relate to the general theory of product family design. At least the descriptive components of this theory generally explain how certain effects such as commonality can be achieved in terms of factors such as module choice. A large number of factors influence this theory and can be placed into three categories of parameters: design, noise, and performance parameters where performance parameters such as cost, reuse, commonality, etc. are a function of both design parameters and noise parameters such as architecture and supply chain issues respectively. This perspective of using a model with these three categories is a model development approach from Otto and Wood (2001) that is appropriate here so that the basic results of the present work can be placed in context. Specifically, the analysis approach is to gather evidence through a case study in terms of the key design parameter of modularity and the key performance parameter of commonality. The particular measures used for these parameters are detailed in the next section. Noise parameters are neglected in this analysis although a relevant consideration for future work that includes this category may involve any factor that generally cannot be controlled by the designer and is essentially an external disturbance that impacts the performance parameter. Examples include customer needs, market segments, external supply chain issues and time. The end result of this experimental approach is to distill this evidence into a heuristic that adds to the general theory of product family design by describing, insofar as the evidence will support, how the performance parameter of commonality is a function of the design parameter of modularity.

4.2 Case Study Analysis

Several commonality measures exist in the literature as indicated in the related work section and although these measures account for multiple factors such as manufacturing commonality, the metrics selected for this study are custom-developed to be usable with the raw data available. More importantly, the purpose of this study is to use measures of commonality for *individual components* rather than the commonality of the product as a whole. The rational for this is simple: we seek to compare platform elements with differentiating elements. This requires knowledge of the commonality of such elements that are comprised of multiple components. In particular, this commonality is evaluated for only select groups of components. For example, the lens among the four variants in the Fuji camera are evaluated together as a set while the lens and the back cover are not combined in the same set for comparison. The following discussion along with Table 3 will address in detail the analysis performed on each component in terms of three main measures: function commonality, physical commonality, and modularity. Appendices A and B provide the remainder of raw data from the analysis.

Functional commonality accounts for the degree of function sharing among a set of comparable components. For example, Table 3 presents data relating to the function commonality of the four back cover parts for the Fuji camera family. For this set of parts, back covers 1-3 are identical while number 4 is distinct. Function commonality for each component is an average of the commonality of each individual function present in the set of parts. Functions are identified based on images of components presented in Thevenot's (2003) work. For the current research, this involves visually examining the photograph of a given component, contemplating its function, and assigning one or more functions to the component as indicated in the Functions Present column in Table 3. The functional basis language was used for function names (Hirtz et al., 2003). Although this allocation of function involves the interpretation of function with some judgment, the degree of error is considered low particularly since the same person is performing this task for all components in this study.

Four unique functions are present among the back covers: Import, Export, Transmit, and Secure. The degree of function commonality of each individual function is determined from how many products utilize a particular function. Considering the "Import hand" as an example, Table 3 shows that "Import hand" exists in all four back cover components. Given that there are four components, the ratio of "Import hand" functionality to the number of components is 1 and is indicated by the 1 shown in the Import Hand Commonality column. Similarly, the "Export light" function is present in only 3 of the four components which gives an Export Light Ratio of 0.75. This function ratio is calculated for each component thus providing an indicator of the commonality for each function among the different components. Given these ratios for each function, an overall function commonality can be computed as the mean average of each individual function commonality. These overall values are listed under Function Commonality.
A function commonality of 1 indicates that all functions present in a given component are present in all of the components being considered while a value of 0 indicates that no commonality exists among the set of components for the given function. For instance, Export Light is only present in back cover 4 which gives

a value of 0 for the function commonality of that particular function as indicated with the 0 shown in the Export Light Commonality column. For this same part, the commonality of two other functions is high which raises the overall function commonality of this component to 0.75.

Table 3. Commonality Example

Part	Functions Present	Function Commonality	Import hand commonality	Import hand	Export light commonality	Export light	Transmit light commonality	Transmit light	Secure film commonality	Secure film	Physical Commonality	Modularity	Function Partitioning	Total Functions	Common Parrts	Overall Commonality
Back cover 1	Import hand, export light, secure film	0.92	1	4	0.75	3	0	0	1	4	0.75	0.3	1	3	3	1.2
Back cover 2	Import hand, export light, secure film	0.92	1	4	0.75	3	0	0	1	4	0.75	0.3	1	3	3	1.2
Back cover 3	Import hand, export light, secure film	0.92	1	4	0.75	3	0	0	1	4	0.75	0.3	1	3	3	1.2
Back cover 4	Import hand, transmit light, secure film	0.75	1	4	0	0	0.25	1	1	4	0.25	0.3	1	3	1	0.8

Determining physical commonality is based on the number of common components within the set under consideration. Three back covers are identical with one being unique, and this is indicated in the 'common parts' heading. In this study, components are either identical or distinct. The resulting physical commonality is calculated as the ratio of common components to the total number of components in the set. For the back cover example, the physical commonality is 0.75 for the three common components and 0.25 for the unique part. For the Fuji family with four variants, the total physical commonality scale ranges from 0.25 (most unique) to 1 (completely common). Given both the function commonality and this physical commonality, an overall commonality can be determined as a distance function of the form: square root of the sum of the squares of both physical and functional commonalities.

Modularity for this work is based on the notion of how well the products are physically partitioned along functional boundaries and is related to the concept of function sharing. This function boundary is defined in the Function Layout Diagram (FLD) and can be interpreted as a spatial region that contains some functionality (Van Wie et al., 2003). This region is equivalent to the "organ" unit as explained by Jensen (2000) in the context of defining Wirk elements from German design theory. The edge of this region is the functional boundary. For example, multiple components (both the front and back cover) share the function of 'import hand.' This implies the 'import hand' function is not physically decomposed along the function boundary because otherwise, the function would be completely contained in one of these parts. Another interpretation is that the 'import hand' function is divided among multiple components. However the 'secure film' function is completely contained in the back cover and is considered to be physically partitioned along functional boundaries. The fact that there is one function (secure film) physically partitioned along a functional boundary is indicated with a 1 in the Function Partitioning column. Modularity is then calculated as the ratio of "function partitioning" to the total number of functions present in the given component. For all components in Table 3, this ratio is 1/3 as shown in the modularity column. The drawback to this approach is that it identifies cases where functions are distributed among multiple components, yet it does not capture how many functions are shared within the component. This information is found in the total number of functions. For both product families in this study, this drawback is perceived as insignificant because the great majority of components are related to only one function with the back cover being one of the few exceptions.

5. Results

The first assessment of the two families examines the relationship among function commonality, physical commonality, and modularity. Figures 1 and 2 illustrate these plots where modularity is indicated by bubble size ranging from 0 to 1 where 1 is modular and 0 is integral. Thus a large bubble is modular while points are integral. Due to the large number of overlapping data points, the numerical instances of a data point are noted near each bubble for each respective bubble size. With this notation, a 7 x 1 indicates that seven data points of bubble size 1 are present at the noted location in the plot.

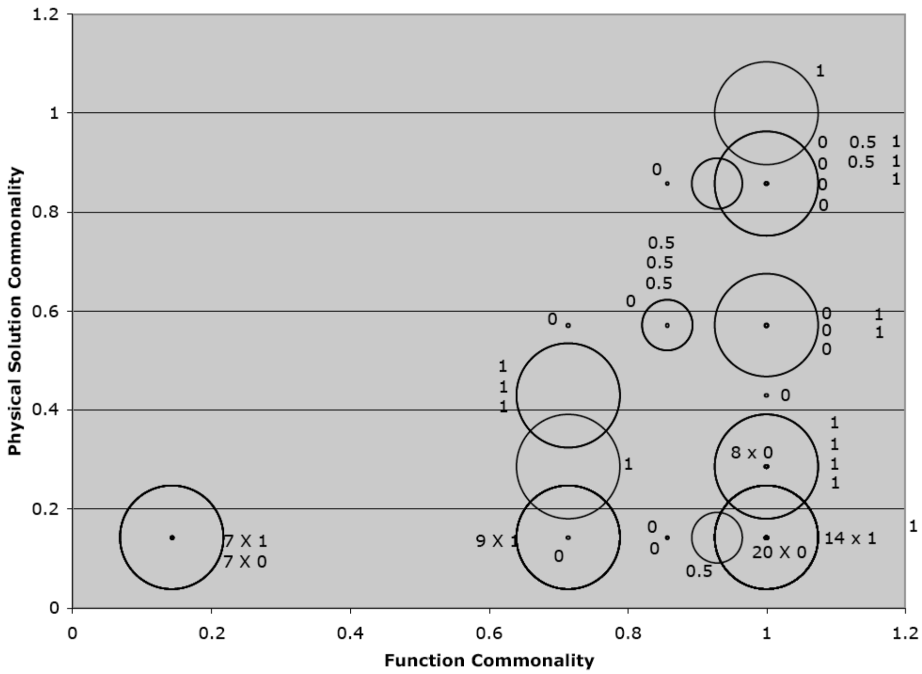


Fig. 1. Commonality and modularity relation for the Kodak camera family

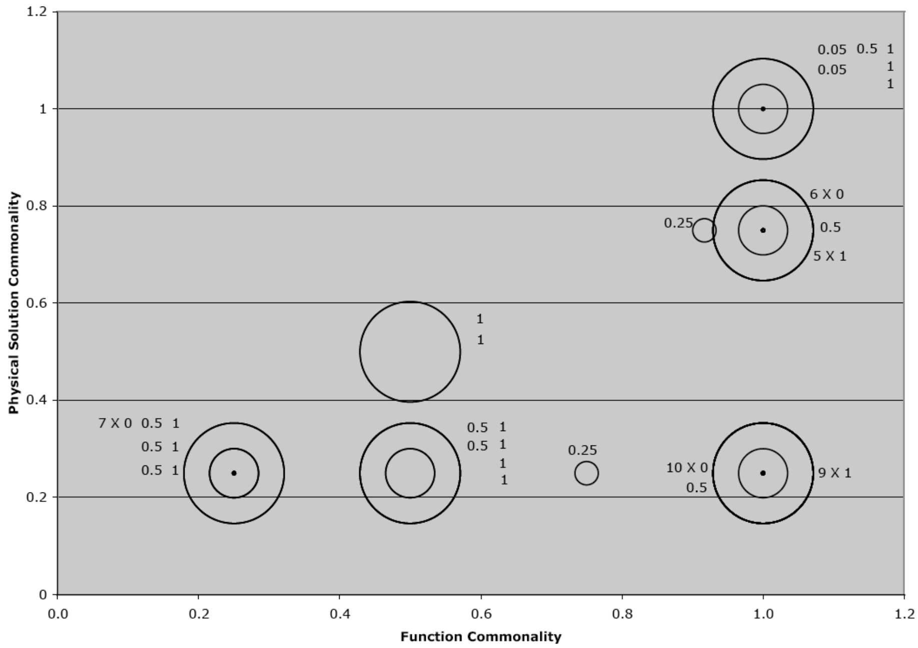


Fig. 2. Commonality and modularity relation for the Fuji camera family

Data from both figures are qualitatively similar although approximately 85% of the components in the Kodak camera family are in the upper half range of overall commonality scale whereas only about 65% for the components in the Fuji camera family. As to the relation between the overall commonality and modularity, this issue is addressed by first ranking the components for each family according to overall commonality. Following this ranking, the modularities of the components within the lower and upper 15% along this overall commonality scale are compared with each other directly. This procedure simply compares the extreme ends of highly common and highly differentiating elements to each other in terms of their differences in modularity. Specifically, the mean averages of modularity for these upper (common components) and lower (differentiating components) groups are determined. The same analysis is performed using the function commonality and the physical commonality in order to identify the differentiating and common components. These results are shown in Table 4.

Table 4. Modularity comparison between common and differentiating components

	Overall commonality		Function commonality		Physical commonality	
	Kodak	Fuji	Kodak	Fuji	Kodak	Fuji
Differentiating	0.68	0.53	0.5	0.53	0.46	0.5
Common	0.41	0.48	0.47	0.48	0.35	0.49
ttest %	98	34	15	23	42	12

The results shown in Table 4 taken as a whole are a mixed bag due to the variation in probabilities for distinct means. Use of overall commonality to identify differentiating and common components produced the greatest distinction between these sets of components in the case of the Kodak camera. In the case showing the highest confidence of distinct means (ttest: 98%), the results show that the differentiating components exhibited a greater degree of modularity than the common components. Again however, the remaining results cloud this finding, and overall the data can be characterized as weakly supporting the hypothesis that differentiating elements are more modular than platform elements. While Table 4 only provides information for the extreme ends of the commonality scale, a visual presentation of the entire set of components along the overall commonality scale is illustrated in Figures 3 and 4.

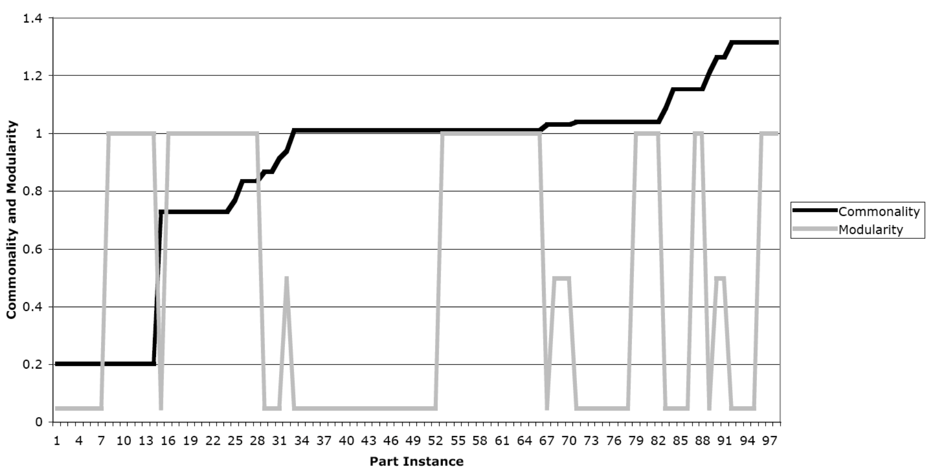


Fig. 3. Overall commonality and modularity for the Kodak camera family

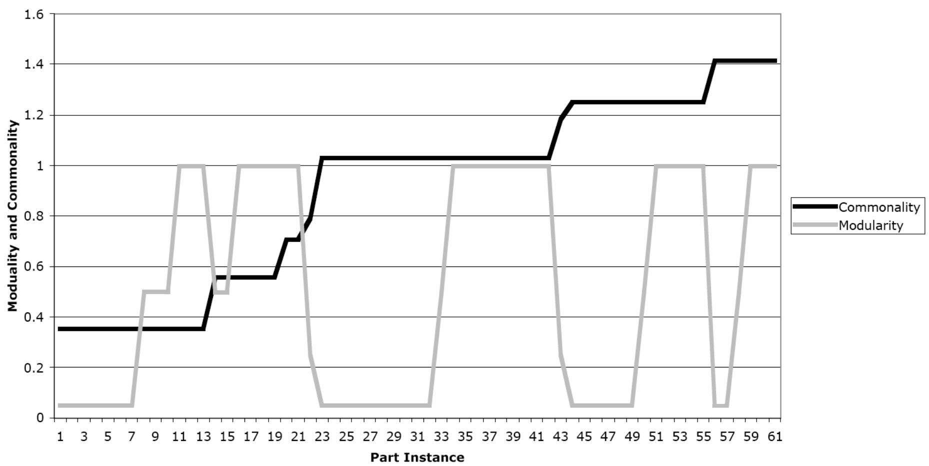


Fig. 4. Overall commonality and modularity for the Fuji camera family

The format of Figures 3 and 4 are given as smoothed lines for the data points associated with each component from each product family. Both plots rank the parts in ascending order according to increasing overall commonality for purposes of visual convenience. Additionally, the metrics of modularity and commonality share the same axis and both are dimensionless. These plots show a more even distribution of parts with various commonalities in the Fuji camera family compared with the Kodak camera family that is more heavily weighted toward the common side of the scale in terms of quantity of components. Additionally, the plots indicate that both modular and integral components are present in roughly similar quantities at medium levels of commonality.

Considering the extreme ends of the commonality scale once more, some other differences are seen in the results beyond the issue of modularity. Table 5 presents the names of components identified as platform and differentiating elements based on the extreme upper and lower 15% tails of components ranked on the overall commonality scale. The first observation is that a variety of component types are found in both platforms and differentiating groups. No readily apparent trend is seen in terms of part type, complexity, scale, or manufacturing process. The second observation is that more of the main product functionality appears to be represented in the platform components than the differentiating elements as shown in Table 5. This is evidenced in parts such as the film, shutter, primary lens, and viewfinder that are critically important while differentiating components such as covers, labels, and rubber bands are less significant to the main functionality of the camera.

Table 5. Platform and differentiating elements

	Kodak	Fuji
Differentiating components	Front cover	Lens cover
	Gear 1	Rubberband
	Gear 2	Rubberband 1
	Switchable viewfinder	Rubber washer
	Washer	Shutter arm
	Waterproof back cover	Waterproof backcover
	Waterproof front cover	Waterproof front cover
	Battery connection	Back ID label
	Bottom cover	Waterproof button
	Film advance wheel 2	Outer advance wheel
	Rubberband	
	Spring 3	
	Spring 4	
	Switchable viewfinder holder	
	Lens 3	
Platform components	Lens 1	Film
	Shutter	Front viewfinder
	Shutter cover	Rear viewfinder
	Exposure counter	Spring 1
	Film	Viewfinder cover
	Arm retainer	Arm 1
	Film advance wheel	Film advance gear
	Film advance wheel	Cam
	Arm 1	Exposure counter
	Arm 2	Lens
	Film advance gear	Shutter spring
	Film advance wheel	
	Cam	
	Spring 1	
	Spring 2	
	Cam	

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6. Discussion

Empirical studies are a useful tool for gathering evidence to study product development methods and in the case of product family design, the scale of data samples for such studies can grow large given that each case under study is a product family that contains multiple products, which in turn consist of several artifacts. Due to this scale issue, the sample set in this study is limited to two product families. Despite this small sample, the results provide insights into how platform and differentiating elements differ and provide some indication of how such analyses can be conducted using measures of commonality and modularity. It is important to note that the analysis performed above with the two camera examples is not intended to serve as a design method. The purpose of the experiment is to simply examine the hypothesis that platform elements are more integral and differentiating elements are more modular. Only the data for the Kodak product family using the measure of overall commonality strongly agrees with this hypothesis. Many reasons are plausible for explaining this result where one reason is that our measures do not account for the multitude of factors that influence the degree of modularity. Ultimately this modularity is driven by many issues beyond commonality. Without fully accounting for these issues, such as a need to use legacy components, the bounds of the hypothesis are difficult to define using the current measures. Inclusion of these factors is difficult in empirical studies where reverse engineering and product teardown is the method of data collection because this approach unfortunately does not directly capture the design rationale of a design team where the decisions leading to the final design are complex. Best practices in engineering require consideration of the context in which the product is designed and this context for the two cameras is not considered in this analysis. The hypothesis is tested only with respect to function and artifact commonality since these are relatively measurable given available data. The measure of modularity used in this work is only one perspective and other measures may provide greater clarity in examining platforms and their counterparts. We note in the results that no obviously apparent trend based on visual inspection is found between platform and differentiating elements with respect to part type, complexity, scale, or manufacturing process. However, these issues were not rigorously measured in this work. It is possible that testing with respect to other aspects such as these could lead to a more complete understanding of the relationship of modularity with platform and differentiating elements. Overall the results suggest that the choice of modular or integral designs in these groups is complex and not entirely explained by the measures used here. In the broad context of product family design, modularity is a factor that can potentially be used to benefit *both* platforms and differentiating elements. Analyses that use improved measures of modularity at perhaps multiple system levels may help clarify how modularity differs between these groups and how modularity can be used to improve designs.

7. Conclusions and Future Work

The objective in this research is to determine if platform elements are generally more integral than differentiating elements. The results weakly support this hypothesis; however, much of the data shows little distinction between platforms and variant parts in terms of modularity. Given the somewhat weak trend, it does seem reasonable to suggest that preference be given to increase commonality of platforms and increase the modularity of differentiating elements. This is also supported by work from Kurtadikar et al. (2004). One note of caution with this suggestion with regard to the results from this paper is that it is based on the premise that the products used in this study are representative of good product family design practice. In a sense, these products are certainly good given their market share although it is not clear how their success is a function of their choice in product platforms and differentiating components. Additionally, these two camera families are not necessarily – and probably not – representative of all products. Results from this work show that several platform elements seem to be related with the main functionality of a product. On the surface this suggests that platform candidates should be sought with primary functionality. Despite this inference, there are many examples of product families utilizing components that make up supporting functionality with platform elements. Fasteners and other supporting functionality OEM components are a prolific common element in many product families. The results do show that several types of components are present in both platform and differentiating groups with no striking trend regarding their type, complexity, scale, or manufacturing process. One potential exception to this is the set of covers found in the differentiating group although some covers are also found with higher degrees of commonality. However, none of the covers were in the group denoted as platform (one cover was just on the border of being included). This is somewhat surprising from a semantic perspective since the covers are the most clear structure or frame or what some might call a platform. At the same time, the covers differentiate each camera as a highly visible outer casing. The wide variety of components in both groups underscores the complexity of platform design and suggests that many factors beyond the issue of modularity play a role.

One of the difficult problems in performing empirical studies on product families is that the logistical tail of acquiring and examining a set of several families can be burdensome since each family contains several products. In this regard, one area of work that may better equip design researchers is a general study of how empirical studies on product families can be devised to be most useful with limited resources. This is analogous to pruning factorial experiments to a manageable set.

As a more specific research issue, the knowledge base that distinguishes platforms from differentiating elements is growing yet far from complete. More study is needed to understand and explain what characteristics are suitable for forming platforms and likewise for differentiating elements. Initial points of interest include factors such as modularity, OEM versus in-house, and time related factors that directly account for product evolution issues.

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Appendix A: Fuji camera data

Nomenclature: ME – mechanical energy; HE – human energy; EE – electrical energy

Part ID	Part Description	Function Commonality	Physical Commonality	Modularity	Function Partitioning	Total Functions	Common Components	Function list	F1 commonality	F1	F2 commonality	F2	F3 Commonality	F3	F4 Commonality	F4	Overall Commonality
1	Arm 1	1	1	0	0	1	4	Transmit ME	1	4	0		0				1.41
2	Arm 2	1	0.75	0	0	1	3	Transmit ME	1	4	0		0				1.25
3	Arm 2	1	0.25	0	0	1	1	Transmit ME	1	4							1.03
4	Backpanel 1	0.92	0.75	0.33	1	3	3	Import hand, export light, secure film	1	4	1	3	0	0	1	4	1.18
5	Backpanel 4	0.75	0.25	0.33	1	3	1	Import hand, transmit light, secure film	1	4	0	0	0	1	1	4	0.75
6	Back ID label	0.25	0.25	0.5	1	2	1	Indicate info, export light	0	1	0	1	0				0.35
7	Battery	0.5	0.25	1	1	1	1	Store EE	1	2	0		0				0.56
8	Battery	0.5	0.25	1	1	1	1	Store EE	1	2	0		0				0.56
9	Waterproof button	0.25	0.25	0.5	1	2	1	Import HE, transmit ME	0	1	0	1	0				0.35
10	Cam	1	1	0.5	1	2	4	Transmit ME, Convert Rot-Linear	1	4	1	4	0				1.41
11	Exposure counter	1	1	1	1	1	4	Indicate info	1	4	0		0				1.41
12	Film	1	0.75	1	1	1	3	Store info	1	4	0		0				1.25
13	Film	1	0.25	1	1	1	1	Store info	1	4	0		0				1.03
14	Film advance gear	1	1	0	0	1	4	Transmit ME	1	4	0		0				1.41
15	Film advance wheel	1	0.75	0.5	1	2	3	Import HE, Tx ME	1	4	1	4	0				1.25
16	Film advance wheel	1	0.25	0.5	1	2	1	Import HE, Tx ME	1	4	1	4	0				1.03
17	Outer advance wheel	0.25	0.25	0.5	1	2	1	Import HE, stop water	0	1	0	1	0				0.35
18	Film base	1	0.75	0	0	2	3	Store film, transmit light	1	4	1	4	0				1.23
19	Film base	1	0.25	0	0	2	1	Store film, transmit light	1	4	1	4	0				1.03
20	Film holder	1	0.75	0	0	1	3	Transmit torque	1	4	0		0				1.25
21	Film holder	1	0.25	0	0	1	1	Transmit torque	1	4	0		0				1.03
22	Flash	0.5	0.5	1	1	1	2	Convert EE to light	1	2	1		0				0.71
23	Flash button	0.5	0.25	0.5	1	2	1	Import HE, transmit ME	1	2	1	2	0				0.56
24	Flash button	0.5	0.25	0.5	1	2	1	Import HE, transmit ME	1	2	0	2	0				0.56
25	Flash cover	0.5	0.5	1	1	1	2	Export light	1	2	0		0				0.71
26	Flash indicator	0.25	0.25	1	1	1	1	Indicate info	0	1	0		0				0.35
27	Flash PCB	0.5	0.25	1	1	1	1	Regulate EE	1	2	0		0				0.56
28	Flash PCB	0.5	0.25	1	1	1	1	Regulate EE	1	2	0		0				0.56
29	Front ID label	1	0.25	1	1	1	1	Indicate info	1	4	0		0				1.03
30	Front ID label	1	0.25	1	1	1	1	Indicate info	1	4	0		0				1.03
31	Front ID label	1	0.25	1	1	1	1	Indicate info	1	4	0		0				1.03
32	Front ID label	1	0.25	1	1	1	1	Indicate info	1	4	0		0				1.03
33	Front panel	1	0.25	0	0	1	1	Import HE	1	4	0		0				1.03
34	Front panel	1	0.25	0	0	1	1	Import HE	1	4	0		0				1.03
35	Front panel	1	0.25	0	0	1	1	Import HE	1	4	0		0				1.03
36	Front panel	1	0.25	0	0	1	1	Import HE	1	4	0		0				1.03
37	Front viewfinder	1	0.75	1	1	1	3	Import light	1	4	0		0				1.25
38	Front viewfinder	1	0.25	1	1	1	1	Import light	1	4	0		0				1.03
39	Lens	1	1	1	1	1	4	Import light	1	4	0		0				1.41
40	Lens cover	0.25	0.25	0	0	1	1	Import light	0	4	0		0				0.35
41	Rear viewfinder	1	0.75	1	1	1	3	Export light	1	4	0		0				1.25
42	Rear viewfinder	1	0.25	1	1	1	1	Export light	1	4	0		0				1.03
43	Rubberband	0.25	0.25	0	0	1	1	Import HE	0	1	0		0				0.35

44	Rubberband 1	0.25	0.25	0	0	1	1	Import HE	0	1	0		0				0.35
45	Rubber washer	0.25	0.25	0	0	1	1	Stop water	0	1	0		0				0.35
46	Shutter	1	0.75	0	0	1	3	Actuate light	1	4	0		0				1.25
47	Shutter	1	0.25	0	0	1	1	Actuate light	1	4	0		0				1.03
48	Shutter arm	0.25	0.25	0	0	1	1	Transmit ME	0	1	0		0				0.35
49	Shutter base	1	0.75	0	0	1	3	Actuate light	1	4	0		0				1.25
50	Shutter base	1	0.25	0	0	1	4	Actuate light	1	4	0		0				1.03
51	Shutter cover	1	0.75	0	0	1	3	Actuate light	1	4	0		0				1.25
52	Shutter cover	1	0.25	0	0	1	1	Actuate light	1	4	0		0				1.03
53	Shutter spring	1	1	1	1	1	4	Store ME	1	4	0		0				1.41
54	Spring	0.25	0.25	1	1	1	1	Store ME	0	1	0		0				0.35
55	Spring 1	1	0.75	1	1	1	3	Store ME	1	4	0		0				1.25
56	Spring 2	1	0.25	1	1	1	1	Store ME	1	4	0		0				1.03
57	Spring 2	0.25	0.25	1	1	1	1	Store ME	0	1	0		0				0.35
58	Viewfinder cover	1	0.75	1	1	1	3	Transmit light	1	4	0		0				1.25
59	Viewfinder cover	1	0.25	1	1	1	1	Transmit light	1	4	0		0				1.03
60	Waterproof backcover	0.25	0.25	0	0	1	1	Stop water	0	1	0		0				0.35
61	Waterproof front cover	0.25	0.25	0	0	1	1	Stop water	0	1	0		0				0.35

Appendix B: Kodak camera data

Part ID	Part Description	Function Commonality	Physical Commonality	Modularity	Function Partitioning	Total Functions	Common Components	Function list	F1 commonality	F1	F2 commonality	F2	F3 Commonality	F3	F4 Commonality	F4	Overall Commonality
1	Arm 1	1	0.86	0	0	1	6	Transmit ME	1	7	0		0				1.32
2	Arm 1	1	0.14	0	0	1	1	Transmit ME	1	7	0		0				1.01
3	Arm 2	1	0.86	0	0	1	6	Transmit ME	1	7	0		0				1.32
4	Arm 2	1	0.14	0	0	1	1	Transmit ME	1	7	0		0				1.03
5	arm retainer	0.86	0.86	0	0	1	6	Transmit ME	1	6	0		0				1.25
6	Back panel	1	0.14	0	0	3	1	Import HE, store film, export light	1	7	1	7	1	7			1.01
7	Back panel	1	0.43	0	0	3	3	Import HE, store film, export light	1	7	1	7	1	7			1.09
8	Back panel	1	0.14	0	0	3	1	Import HE, store film, export light	1	7	1	7	1	7			1.01
9	Back panel	1	0.14	0	0	3	1	Import HE, store film, export light	1	7	1	7	1	7			1.01
10	Back panel	1	0.14	0	0	3	1	Import HE, store film, export light	1	7	1	7	1	7			1.01
11	Battery	0.71	0.43	1	1	1	3	Store EE	1	5	0		0				0.83
12	Battery	0.71	0.14	1	1	1	1	Store EE	1	5	0		0				0.73
13	Battery	0.71	0.14	1	1	1	1	Store EE	1	5	0		0				0.73
14	Battery connection	0.14	0.14	1	1	1	1	Transmit EE	0	1	0		0				0.2
15	Bottom cover	0.14	0.14	1	1	1	1	Secure film	0	1	0		0				0.2
16	Button	0.86	0.57	0.5	1	2	4	Import HE, transmit ME	1	6	1	6	0				1.03
17	Button	0.86	0.57	0.5	1	2	4	Import HE, transmit ME	1	6	1	6	0				1.03
18	Button	0.86	0.57	0.5	1	2	4	Import HE, transmit ME	1	6	1	6	0				1.03
19	Cam	1	0.86	1	1	1	6	Convert rot to linear	1	7	0		0				1.32
20	Cam	1	1	1	1	1	7	Convert rot to linear	1	7	0		0				1.41
21	Exposure counter	1	0.57	1	1	1	4	Indicate info	1	7	0		0				1.15
22	Exposure counter	1	0.29	1	1	1	2	Indicate info	1	7	0		0				1.04
23	Exposure counter	1	0.14	1	1	1	1	Indicate info	1	7	0		0				1.01
24	Film	1	0.57	1	1	1	4	Store info	1	7	0		0				1.15
25	Film	1	0.14	1	1	1	1	Store info	1	7	0		0				1.01
26	Film	1	0.14	1	1	1	1	Store info	1	7	0		0				1.01
27	Film	1	0.14	1	1	1	1	Store info	1	7	0		0				1.01
28	Film advance gear	1	0.86	0	0	1	6	Transmit ME	1	7	0		0				1.32
29	Film advance gear	1	0.14	0	0	1	1	Transmit ME	1	7	0		0				1.01
30	Film advance wheel	0.93	0.86	0.5	1	2	6	Import HE, transmit ME	1	6	1	7	0				1.26
31	Film advance wheel	0.93	0.86	0.5	1	2	6	Import HE, transmit ME	1	6	1	7	0				1.26
32	Film advance wheel	1	0.86	0	0	1	6	Transmit ME	0	0	1	7	0				1.32
33	Film advance wheel	0.93	0.14	0.5	1	2	1	Import HE, transmit ME	1	6	1	7	0				0.94
34	Film advance wheel 2	0.14	0.14	1	1	1	1	Import HE	0	1	0		0				0.2
35	Film base	1	0.14	0	0	3	1	Store film, transmit light, transmit ME	1	7	1	7	1	7			1.01
36	Film base	1	0.14	0	0	3	1	Store film, transmit light, transmit ME	1	7	1	7	1	7			1.01
37	Film base	1	0.14	0	0	3	2	Store film, transmit light, transmit ME	1	7	1	7	1	7			1.04
38	Film base	1	0.29	0	0	3	2	Store film, transmit light, transmit ME	1	7	1	7	1	7			1.04

39	Film base	1	0.14	0	0	3	1	Store film, transmit light, transmit ME	1	7	1	7	1	7			1.01
40	Film holder	0.86	0.57	0	0	1	4	Transmit torque	1	6	0		0				1.03
41	Film holder	0.86	0.14	0	0	1	1	Transmit torque	1	6	0		0				0.82
42	Film holder	0.86	0.14	0	0	1	1	Transmit torque	1	6	0		0				0.82
43	Flash	0.71	0.43	1	1	1	3	Convert EE to light	1	5	0		0				0.83
44	Flash	0.71	0.14	1	1	1	1	Convert EE to light	1	5	0		0				0.73
45	Flash	0.71	0.14	1	1	1	1	Convert EE to light	1	5	0		0				0.73
46	Flash cover	0.71	0.43	1	1	1	3	Export light	1	5	0		0				0.83
47	Flash cover	0.71	0.14	1	1	1	1	Export light	1	5	0		0				0.73
48	Flash cover	0.71	0.14	1	1	1	1	Regulate EE	1	5	0		0				0.73
49	Flash PCB	0.71	0.14	1	1	1	1	Regulate EE	1	5	0		0				0.73
50	Flash PCB	0.71	0.29	1	1	1	2	Regulate EE	1	5	0		0				0.72
51	Flash PCB	0.71	0.14	1	1	1	1	Regulate EE	1	5	0		0				0.73
52	Flash PCB	0.71	0.14	1	1	1	1	Import light	1	5	0		0				0.73
53	Front cover	0.14	0.14	0	0	1	1	Import HE	0	1	0		0				0.2
54	Front panel	1	0.14	0	0	1	1	Import HE	1	7	0		0				1.01
55	Front panel	1	0.14	0	0	1	1	Import HE	1	7	0		0				1.01
56	Front panel	1	0.29	0	0	1	2	Import HE	1	7	0		0				1.04
57	Front panel	1	0.14	0	0	1	1	Import HE	1	7	0		0				1.01
58	Front panel	1	0.14	0	0	1	1	Import HE	1	7	0		0				1.01
59	Front panel	1	0.14	0	0	1	1	Import HE	1	7	0		0				1.01
60	Gear 1	0.14	0.14	0	0	1	1	Transmit ME	0	1	0		0				0.2
61	Gear 2	0.14	0.14	0	0	1	1	Transmit ME	0	1	0		0				0.2
62	ID label	1	0.14	1	1	1	1	Indicate info	1	7	0		0				1.01
63	ID label	1	0.14	1	1	1	1	Indicate info	1	7	0		0				1.01
64	ID label	1	0.14	1	1	1	1	Indicate info	1	7	0		0				1.01
65	ID label	1	0.14	1	1	1	1	Indicate info	1	7	0		0				1.01
66	ID label	1	0.14	1	1	1	1	Indicate info	1	7	0		0				1.01
67	ID label	1	0.14	1	1	1	1	Indicate info	1	7	0		0				1.01
68	Lens 1	1	0.29	1	1	1	2	Import light	1	7	0		0				1.04
69	Lens 1	1	0.57	0	0	1	4	Import light	1	7	0		0				1.15
70	Lens 1	1	0.14	0	0	1	1	Import light	1	7	0		0				1.01
71	Lens 2	0.71	0.57	0	0	1	4	Import light	1	5	0		0				0.91
72	Lens 3	0.71	0.14	0	0	1	1	Import light	1	5	0		0				0.73
73	Lens cover	1	0.29	0	0	1	2	Transmit ME	1	7	0		0				1.04
74	Lens cover	1	0.29	0	0	1	2	Transmit ME	1	7	0		0				1.04
75	Lens cover	1	0.29	0	0	1	2	Transmit ME	1	7	0		0				1.04
76	Lens cover	1	0.14	0	0	1	1	Transmit ME	1	7	0		0				1.01
77	Rubber band	0.14	0.14	1	1	1	1	Import HE	0	1	0		0				0.2
78	Shutter	1	0.29	0	0	1	2	Actuate light	1	7	0		0				1.04
79	Shutter	1	0.57	0	0	1	4	Actuate light	1	7	0		0				1.15
80	Shutter	1	0.14	0	0	1	1	Actuate light	1	7	0		0				1.01
81	Shutter cover	1	0.29	0	0	1	2	Actuate light	1	7	0		0				1.04
82	Shutter cover	1	0.57	0	0	1	4	Actuate light	1	7	0		0				1.15
83	Shutter cover	1	0.14	0	0	1	1	Actuate light	1	7	0		0				1.01
84	Spring 1	1	0.86	1	1	1	6	Store ME	1	7	0		0				1.32
85	Spring 1	1	0.14	1	1	1	1	Store ME	1	7	0		0				1.01
86	Spring 2	1	0.86	1	1	1	6	Store ME	1	7	0		0				1.32
87	Spring 2	1	0.14	1	1	1	1	Store ME	1	7	0		0				1.01
88	Spring 3	0.14	0.14	1	1	1	1	Store ME	0	1	0		0				0.2
89	Spring 4	0.14	0.14	1	1	1	1	Store ME	0	1	0		0				0.2
90	Swtchble vwfndr hldr	0.14	0.14	1	1	1	1	Restrict DOF	0	1	0		0				0.2
91	Swtchble vwfndr hldr	0.14	0.14	0	0	1	1	Export light	0	1	0		0				0.2
92	Viewfinder	1	0.29	1	1	1	2	Export light	1	7	0		0				1.04
93	Viewfinder	1	0.29	1	1	1	2	Export light	1	7	0		0				1.04
94	Viewfinder	1	0.14	1	1	1	1	Export light	1	7	0		0				1.01
95	Viewfinder	1	0.14	1	1	1	1	Export light	1	7	0		0				1.01
96	Viewfinder	1	0.14	0	0	1	1	Export light	1	7	0		0				1.01
97	Washer	0.14	0.14	0	0	1	1	Stop water	0	1	0		0				0.2
98	Waterproof backcover	0.14	0.14	0	0	1	1	Stop water	0	1	0		0				0.2

99	Waterproof front cover	0.14	0.14	0	0	1	1	Stop water	0	1	0		0				0.2