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Design Roadmapping: A Framework and Case Study on Planning Development of High-Tech Products in Silicon Valley

We propose a framework for design roadmapping that parallels existing product roadmapping and technology roadmapping processes. It leverages three needs we have observed in organizations as they use existing roadmapping processes: (1) to focus on development of customer and user experiences (UX), not just on features; (2) to increase engagement of designers early in the planning process; and (3) to provide a means for rapidly responding to changes in the environment. Design roadmapping is an attempt to reconcile differences that arise when customer/user needs are not considered simultaneously with technology choices. The proposed design roadmapping process assists project prioritization and selection. The process aggregates design experience elements along a timeline that associates key user needs with the products, services, and/or systems the organization wishes to deliver. To illustrate the design roadmapping process, we conducted a case study in which we applied the design roadmapping process to projects undertaken by a large corporation's innovation lab located in research centers in San Francisco and Mountain View, CA, in partnership with corporate stakeholders located in Asia. The five-step design roadmapping procedure is provided along with detailed information. The decisions from the design roadmapping process have been incorporated into the company's commercial plans. Key findings in this corporate case study bolster the positive impact of design roadmapping in moving strategic thinking from a technology/feature-driven process to one that is design/experience-driven. It shows how firms might weigh choices between user needs, design principles, and technological innovation.
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Introduction

Product and technology roadmapping processes have been discussed for several decades in the academic literature as a tool for product planning [1–4] and have been used effectively in industry to guide the interactive development of products and technologies across an organization [5]. Phaal and Muller [6] describe roadmapping as an iterative process of ideation, divergence, convergence, and synthesis, and introduce an architecture for roadmapping with multiple hierarchical layers. Vähäniitty et al. [7] suggest the following steps for creating and updating product roadmaps: define strategic vision, scan the environment, revise and distill the product vision, estimate the product life cycle, and evaluate the planned development efforts. Portfolio planning, of which product and technology roadmapping are a part, aims to align the organization's investments to maximize returns, create strategic fit, and balance risk [1]. Roadmapping, in turn, lays out those investments over time. Projects from the portfolio plan or roadmap are then fed into new product development processes such as the stage-gate process [8,9] and waterfall development processes [10]. Creating product family maps that leverage a series of platforms (product, technology, brand, etc.) over time allows a company to create a series of successive product concepts with new features and enhanced capabilities [11]. The main focus of these activities is to sustain market leadership over time by leveraging technological advances into products that provide greater efficiency, cost reduction, new features, etc.

Traditional portfolio planning, roadmapping, and product development processes worked well in market environments that were relatively predictable. Rapidly evolving technologies [12] and shifting user expectations, however, are challenging traditional methods. New approaches to product development that integrate new customer understanding in near real-time are replacing traditional stage-gate and waterfall development processes. These include learning-based innovation approaches [13,14] and agile development methods [15]. These more adaptive, flexible, and accelerated new product development processes demand new approaches to portfolio planning and roadmapping.

Recent roadmapping process research attempts to make roadmapping more visual and interactive. Kerr and Phaal [16] emphasize a design-driven approach and visual representation of roadmaps for clearer communication among stakeholders. Simonse et al. [17] present a conceptual framework that emphasizes visualization of market, product, and technology plans over time. This work creates more interactive means of working with roadmaps, making them both visual to teams working together and providing greater ease for updating them over time. They do not, however, reflect subjective attributes such as user experiences.

We have developed a design roadmapping process that allows a team to envision how a concept might evolve to meet upcoming market conditions. The design roadmap associates key user needs with the products, services, and/or systems that the organization aims to develop over time. The design roadmap can be integrated with project selection and prioritization processes to guide how

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and when the design experience elements should be kept or discarded.

The design roadmapping process adheres to three principles derived from prior research [18]: (1) focus on development of customer and user experiences, not just on features; (2) increase engagement of designers early in the planning process; and (3) provide a means for rapidly responding to changes in the market environment.

Design Roadmapping: Putting User Experience First

Design roadmapping is a way to embed user experience goals into the earliest stages of conceptual design. This new approach is the result of primary feedback from semistructured interviews (35 interviews with 18 Silicon Valley firms) in prior research [18], where attempts to bring user experience into roadmapping have been observed as a reaction to fluctuating market conditions. The design roadmapping tools presented in this paper support the initial planning activities of the product development process.

We define the design roadmap as a canvas that positions expected core user experience design elements along a timeline and then associate them with products, services, and/or systems the organization wishes to deliver [18]. Similar to conventional product and technology roadmap templates [5], our design roadmap uses the *x*-axis to represent the timeline from present to future and the *y*-axis to represent design elements. The design roadmap integrates information from a traditional technology roadmap, which shows the progression of technologies over time, and a product roadmap, which shows product characteristics over time.

Responses from our previous research demonstrated that roadmapping participants aspire to include subjective elements, such as user experiences, desired outcomes, and user needs, which are not covered in conventional technology and product roadmapping processes.

We formulated the design roadmapping process to respond to these interests, focusing on user experiences and form factors, as they were the most frequently requested design elements [18]. Thus, the elements of our *y*-axis comprise several layers of user experiences (the highest level to the lower levels) and different form factors. The layers of experience levels—from overall user experience to detailed experience—on the *y*-axis force an organization to clearly articulate the relationships among them and facilitate making complementary choices.

An example template reproduced by the authors after the completion of the case study is shown in Fig. 1. Most importantly, the design roadmapping template is defined to be flexible and responsive to changes that might be required as the design team works through product development after the initial design roadmapping exercise. This allows the design roadmapping process to be iterative and reflect emerging market needs and user inputs as new data accumulate, in contrast to traditional roadmapping approaches which tend to be completed at a defined point in time. The value of building a design roadmap comes not only from the initial design roadmap itself but also from the conversations involved in the process.

We tested the roadmapping process through a case study in a global company with corporate stakeholders located both in Silicon Valley and in Asia. The case study addressed an early-stage product development effort focused on selection of product concepts that range from highly technology-driven to less technology-driven.

Research Objective

Our research aims to create a design roadmapping framework based on understanding on how multidisciplinary teams collaborate, communicate, and frame problems and opportunities ahead of the product development process. It focuses on how teams engage in portfolio planning and roadmapping to establish their goals, visions, and processes, and how they make decisions around the allocation of resources to projects driven by user experience criteria. The teams we examine in this paper are not only cross-disciplinary, but also work across organizational boundaries between corporate and remote entities. Based on our understanding of the use of roadmapping today, we constructed a design roadmapping framework and steps for project selection that enable designers, engineers, and other innovators to augment their existing design processes.

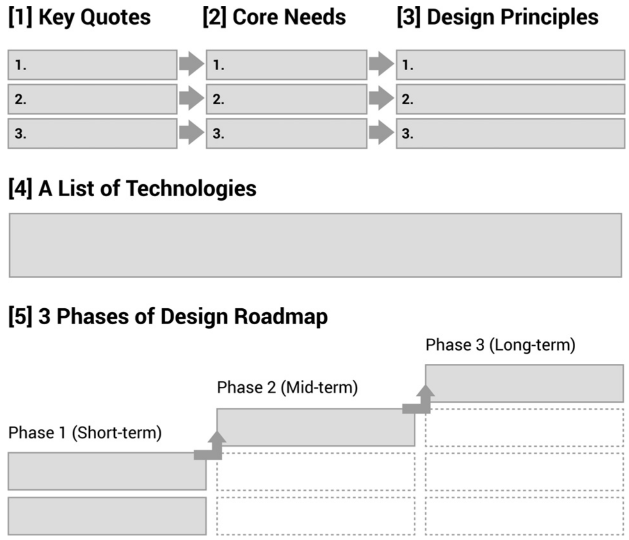

Fig. 1 Example design roadmapping template produced by the authors after the case study

Research Methodology

The case study presented in this paper is the result of in-depth interviews, observations, and a case study implementation conducted by researchers embedded as employees at a San Francisco innovation center responsible for user experience-driven innovation of consumer electronic products in a large, global technology company headquartered in Asia. Direct quotes from interviews and observations were collected and analyzed using grounded theory [19,20] and content analysis to build design roadmapping frameworks. Zimmerman et al. [21] illustrate the connections and deliverables among design researchers and practitioners within the human–computer interaction (HCI) field. They argue that a prototype/research artifact plays a crucial role as a medium for a development team to demonstrate an unexplored concept to other stakeholders within an organization. Similarly, we analyzed artifacts such as project proposals, design reviews, roadmaps, presentation slides, and user research data from existing portfolio planning and roadmapping processes. Finally, we tested our theory and frameworks with individuals in the organization through design roadmapping workshops and close participation during one entire product planning cycle. Our research incorporated four phases: phase 1—in-depth interviews (May 2014—August 2014); phase 2—observations (May 2014—December 2014); phase 3—case study implementation of the new design roadmapping process (August 2014—February 2015); and phase 4—postinterviews and wrap up (March 2015—May 2015).

Due to confidentiality agreements with the company, we present specific findings as general insights, but are required to omit descriptions of the specific technologies and design features under consideration.

In-Depth Interviews. We dive deeply within one organization as a case study in which we conducted 11 interviews, each of 30–60 min duration, with professionals in two innovation labs.

Table 1 Summary of case interview participants

	Designers	Engineers	Managers
Number of interviews	Five	Three	Three
Job categories	User interface designer, user experience designer, industrial designer, and design researcher	Mechanical engineer, software engineer, and prototyper	Product manager and design manager

The interviewees—identified by job category in Table 1—were key players in ongoing projects, who were able to provide real-time perspectives on their experience with the planning process. These interviews build on our prior work to understand roadmapping processes today that was based on 35 interviews with representatives of various functional areas within 18 different companies [18].

All interviewees had ownership in their project outcomes and were key decision-makers throughout the new product development process. Interviews were performed both in-person (eight interviews) and remotely via Skype (three interviews). We conducted follow-up interviews after the design roadmap interventions with three project leads to discuss the outcomes of the design roadmapping process.

Observations. We observed approximately 20 professionals in contexts such as team meetings and conference calls. We observed approximately 41 design meetings where multidisciplinary team members discussed their projects, each of which lasted approximately 30 min to 1 h. The observers captured key conversations, topics, themes, and controversial arguments in each meeting. With participant permission, these observations were simultaneously noted and subsequently drawn into reasoned design roadmapping frameworks. Our observations helped us understand how team members collaborated and what types of tangible and intangible artifacts were exchanged during the design process.

Case Study Implementation. After 4 months of interviews and 8 months of observation to understand the existing processes employed by the company, we implemented our design roadmapping process to augment the processes already in use. We made an oral introduction of the proposed process to team members who were still at the early stage of design concept development.

The five steps of design roadmapping shown in Table 2 were introduced through an additional three workshops. In addition, design roadmapping templates were shared with the three teams (of three to four members each) participating in the case studies. Our lead researcher spent approximately 10 h with each team, examining each team's progress using the design roadmapping process and conducting postinterviews to reflect on our suggested framework afterward.

Data Analysis. We collected 107 pages of full interview scripts and 12 pages of observation notes over 8 months. Using grounded theory [19,20] to analyze our observation and interview data and refine our analyses, we created transcriptions from which we highlighted, interpreted, and extracted keywords and key quotes. Three researchers worked in parallel; the results and insights of their individual analyses were then merged into one consolidated document. Project deliverables and other artifacts were subsequently examined to further comprehend the context of meetings and interviews. This process allowed us to fully document the new design roadmapping framework and the changes it made to the existing product development process and team collaboration practices. The backdrop and descriptive findings for the case study are presented herein.

Case Study

The group we collaborated with to apply our design roadmapping process consisted of employees who were assigned to three independent design projects. The main function of the group was to create innovative early concepts that would ultimately be scaled for mass commercialization. Each of the three design projects was launched 3 months prior to our arrival.

Existing Corporate Design Process. In this company, the scope/goal of each design project is set every year by mutual agreement between the corporate headquarters and the innovation group of which the three case study projects are a part. Each project was simultaneously working toward the same objective: design a new consumer display concept for 3–5 yr in the future. The teams aimed to create an ideal, yet realizable, user experience irrespective of cost. Each project team was multidisciplinary, including at least one user interaction/user experience designer, one engineer/prototyper, and one design researcher who was responsible for user research over all three projects. The goals of the three projects—P, W, and M—are shown in Table 3.

The roadmapping intervention described herein augmented the three stages of the company's existing design process, outlined in Table 4: project scoping, prototyping/testing, and refining/

Table 2 Five steps of the design roadmapping process

	Description	Sources of step
1	Gather comprehensive data on users, users' experience, and trends	Conduct selective in-depth interviews; behavioral observations for unexplored needs and opportunity spaces for innovation; comprehensive online surveys; expert interviews; trend report reviews
2	Extract core design principles from the user needs, experiences, and trends	Synthesize data to create common themes and insights and extract core design principles. Narrow user group focus. Find pain points. Create primary and secondary personas and use scenarios. Record key observations and data from these personas and use scenarios
3	Gather an exhaustive list of technologies containing core feature sets of the design concept and prioritize them	Research existing technologies and functionalities. Brainstorm potential new features. Prioritize the technologies that best support core feature sets of the design concept. Select which technologies would be beneficial and useful for the target personas
4	Map projects to design principles	Prioritize technologies based on design principles that stem from themes and insights, and examine how technologies can be applied to address opportunity spaces and pain points of target user groups. Rate projects relative to design principles.
5	Create design roadmap	Combine elements from user research and technology analysis to map out a plan that integrates human-centered solutions with targeted technologies of core feature sets for a design concept. Create a cohesive collective shared vision for a design team.

Table 3 Goals of three projects in the case study

Project name	Description
Project P	Reflect on the flowing stream of everyday life to strengthen family connections and shared identity
Project W	Explore various forms of (tele) presence, leveraging the screen's facility to mediate casual long-duration engagements between remote people and distant places
Project M	Explore how full-body interactions, augmented reality, and faceted media manipulation can unlock realms of fantasy, storytelling, and imaginative play

Table 4 Three stages of design processes in case study

Design process	Descriptions
Project scoping	Research user cases and scenarios in the real world to find high value opportunities/applications. Identify user experience principles to guide explorations.
Prototyping and testing	Evaluate scenarios to identify core user experiences and features that are required for designing new products and services. Build short-sprint minimum viable products (MVPs) and test them with target user segments.
Refining and documentation	Iteratively refine the seed products that demonstrate value and scale up to achieve a broader vision of the project. Create demonstration and documentation to assure successful knowledge transfer.

documentation. In the first step, the project scope is defined. Then, the user experiences and scenarios are developed and evaluated by internal members through rapid prototyping. Finally, refinements of these concepts are integrated into both tangible (e.g., sketches, mock-ups, and prototypes) and intangible (e.g., code and interaction architectures) deliverables, and a full package of documents (e.g., specifications, presentation slides, written documents, and videos) is delivered to internal collaborators. Our interventions were applied across all three stages.

Once these three steps are completed, the ideas, concepts, and insights obtained from the company's innovation centers in Silicon Valley are shared with personnel in corporate headquarters in Asia who are responsible for development through concept feasibility and commercialization.

Applying the Design Roadmapping Framework in the Case Study. As this was the first time the company participants had performed design roadmapping, the design roadmapping framework and process were introduced gradually—first to the three project leads and then through team workshops and individual sessions. The five steps of the design roadmapping process are explained in detail below.

Step 1: Gather comprehensive data on users, users' experiences, and trends

Data from various user studies by both this group and headquarters' groups were collected. As part of the pre-existing design processes, expert interviews were conducted with market leaders to give the project teams insights about megatrends and how these might affect user lifestyles in the near future. All design teams also reviewed reports from external channels, such as Intel's Trend Report 2014, Gartner's Hype Cycle Reports 2013 and 2014, IEEE's 2022 CS Report, Goldman Sachs' IoT reports, and the like. Qualitative user research data collected by a skilled internal design researcher became a valuable source for further analysis as well. This research was synthesized by an embedded lead researcher, a skilled internet design researcher, and three design project leads, into 50 user experience themes with primary keywords that represented user trends.

Step 2: Extract core design principles from user needs, experiences, and trends

From the 50 user experience themes and market trends identified in step 1, 12 design principles were extracted as key drivers for the design work. These 12 design principles were defined by internal team members. The extracted design principles were prioritized by frequency of occurrence (measured as a percentage of data points). Labels for the 12 core design principles, listed below, are evocative of common characteristics:

- Empowered data: Streamlined/distilled data usage enriches a person's life (22%).
- Technology-empowered experience: Technology can be developed to enhance human life experiences (e.g., Oculus lift, Google Glass, etc.) (15%).
- Authenticity: Overexposure to reproduced data triggers appreciation of the original (11%).
- Co-existence/mixture/transition: Two different worlds live together (e.g., analog/digital, inside/outside, input/output, and internal/external) (9%).
- Communication network: Human-to-human, device-to-device communication for co-activities, collaboration, cowatching, comedia consumption, or simply being connected in a close loop (9%).
- Physical representation: Long history of analog experience (e.g., paper) triggers analoglike digital interaction (7%).
- Mobile experience: Seamless "on-the-go" experience extended from stationary experience (7%).
- Anticipatory computing: Data collected from multiple sensors and devices provide appropriate recommendations regarding future needs and user behaviors (6%).
- Software-based device control: Control over device based on intangible interaction (4%).
- Minimal/ambient interaction: Having more features and experience on top of previous experience motivates users to admire simplicity (4%).
- Data storage paradigm shift: Confidential data storage from device to cloud (4%).
- Privacy/security: Nonintrusive means of technology integration maintains a secured feeling of privacy (2%).

Step 3: Gather an exhaustive list of technologies containing core feature sets of the design concept and prioritize them

While the prior two steps focus on capturing customer and user needs, particularly as projected into the future, this step examines the technologies that are available to deliver those experiences. Across the three design projects—P, W, and M—the project leads, who had full knowledge and expertise on each project, identified and documented 83 subtechnologies that contained the core feature sets of the three design concepts. These subtechnologies were derived based on the user experiences they wanted to develop. The combination of these technologies defined the desired experiences for each design project. The project leads then categorized them by the development time that they would require: short-term (1–2 yr), midterm (3–5 yr), and long-term (more than 5 yr). Short-term technologies accounted for 42% of the total, midterm for 41%, and long-term for 17% (Table 5). Various factors affected how each project team determined which technologies were short-, medium-, or long-term: the priority placed on the user experiences to be developed, technology feasibility, bill of material costs, and completeness of user scenarios at that moment.

Table 5 shows that the percentages of technologies in both the short- and midterm are similar. Although the first priority for the project lead was to create the most compelling concept for the short term, a significant number of concepts, experiences, and features that could not be implemented in the first phase were kept in a repository for further development in following phases. This step identifies times when the subtechnologies immediately

Table 5 Number of technologies identified for each project concept by each project lead

	Project P	Project W	Project M	Sum (%)
Short-term	19	8	8	35 (42)
Midterm	15	8	11	34 (41)
Long-term	5	5	4	14 (17)
Sum	39	21	23	83 (100)

Table 6 Project ratings by design principle (full list of rating comparison can be found in Appendix A)

	Project P	Project W	Project M
Empowered data	51	39	15
Technology empowered experience	31	23	19
Communication network	20	15	14
Co-existence/mixture/transition	16	13	7
Physical representation	7	10	3
Anticipatory computing	14	13	3
Minimal interaction	10	9	6
Authenticity	13	10	9
S/W-based device control	7	7	4
Privacy/security	2	4	0
Mobile experience	11	9	6
Data storing experience shift	8	5	4
Sum	190	157	90

needed may not be available and how availability of necessary technologies may influence creating the desired user experiences for different phases.

Step 4: Map projects to design principles

The three projects (shown in Table 3) were evaluated against the list of 12 design principles by the team members using a six-point Likert scale (0: not at all related, 1: barely related, 2: somewhat related, 3: related, 4: closely related, and 5: highly related). The resulting scores were multiplied by the weight assigned to each design principle from the user and trend research and summed to create the scores shown in Table 6. Ratings were analyzed to compare differences and similarities among ongoing design projects, so as to figure out possible directions whether to include the projects or not and how to depict key design principles of three projects in insightful roadmaps. While all three projects had similar profiles, the magnitudes of their scores differed.

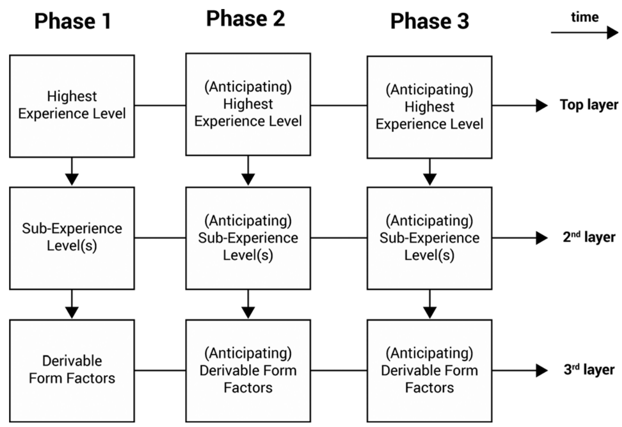

Fig. 2 Schematic design roadmapping, illustrating distinct experience level from highest (top layer) to sublevel (second layer), and derivable form factors (third layer) by each project aligned to time phases

Project P outscored project W, and both significantly outscored project M.

Step 5: Create design roadmap

This step combines design elements from the user research completed in steps 1 and 2 and the technology analysis described in steps 3 and 4. Throughout the final step of design roadmapping implementation, participants map out a plan that integrates human-centered solutions with targeted technologies in order to create a cohesive, collective shared vision and experience for a design team to follow over time. To create this design roadmap, we define two levels of user experience in two layers and derivable form factors in the other layer across time periods to create the nine boxes shown in Fig. 2.

The top layer is a short description of the overarching experience. The second layer details the subexperiences that form the highest experience level. The different experience level is depicted along with derivable form factors: product, service, or system in the third layer. These layers are defined by team members, taking into account the new information from design research results, user trends, technical feasibility, etc., to show the progressive evolution of design elements.

The design concepts can be evolved to expand their experiences in various types of form factors. Table 7 depicts the progressive

Table 7 The level of experience to be accomplished is defined prior to a phase of technology exploration

Experience level	Project P	Project W	Project M
Short-term	Family reflection	Open connections	Content generation
Midterm	Understand family and individuals; anticipatory customization	Enriched connections	Add-on evolution kit bundling stand-alone
Long-term	Technology improved connectedness	Seamless connections	Sharing generated contents
Description	Project P's short-term goal is to provide a digital artifact that enables frequent reflections on family identity, heritage, and well-being. This concept evolves in the next phase with enhanced experiences for better family understanding. Finally, the long-term goal is reflected in technology-driven experiences that can be customized to anticipate individual family needs.	Project W's short-term goal is to connect people remotely apart through displays. The experience was enhanced by enriched technologies for emotional connections and the fundamental goal is to aim for making a seamless connections.	Project M's short-term goal is to engage users in content generation via a technology-driven tool. The design concept has evolved to expand it to various types of form factors. The fundamental goal of this project is to make it as a platform that allows users to share the contents with other connected users via the online space.

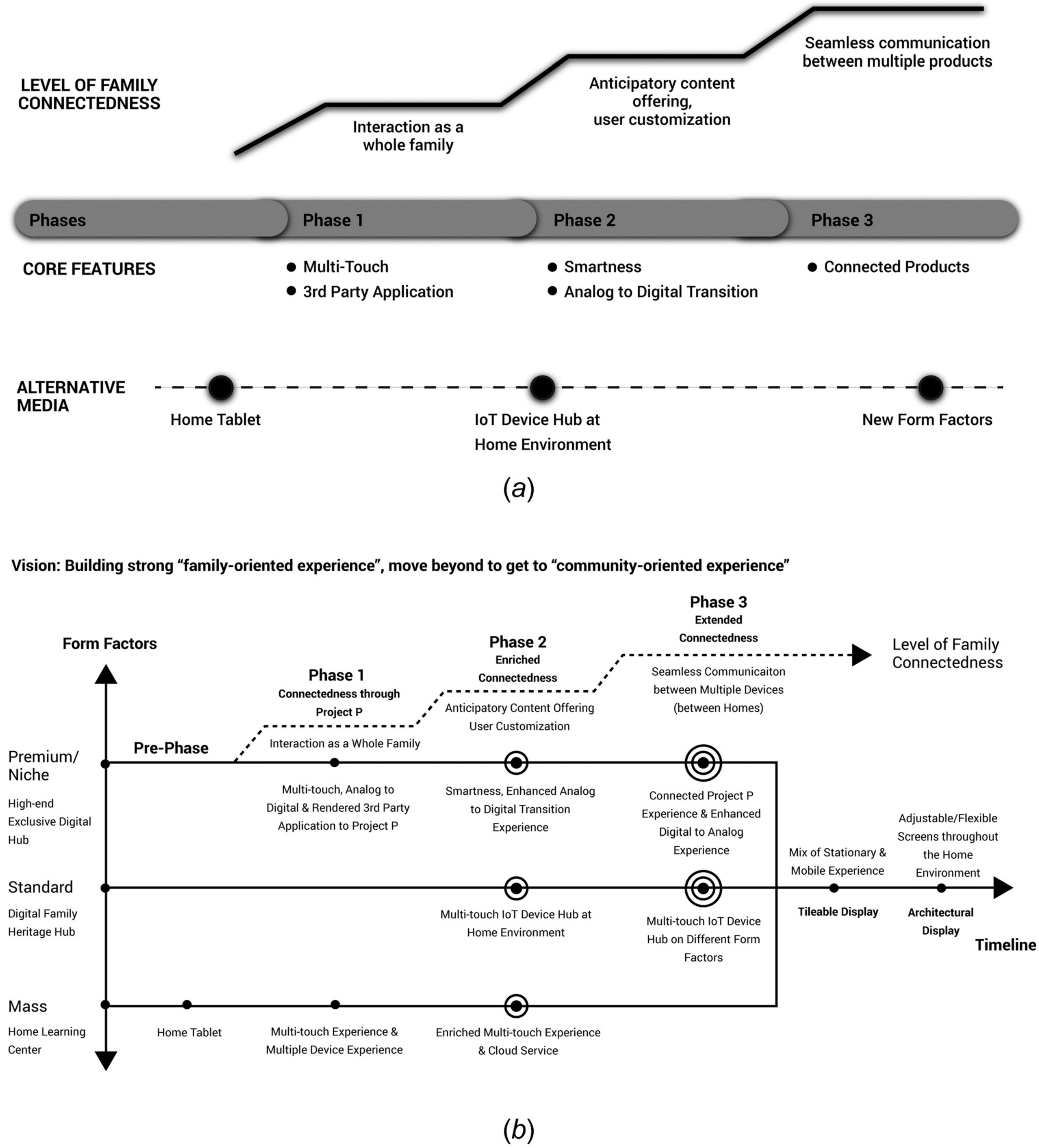

Fig. 3 Project P design roadmaps: the simplified version (top) and the detailed version (bottom)

level of experience defined by each project and its description. A sample roadmap from project P is depicted in Fig. 3. The final roadmaps created by project leads were refined several times as each project moved forward. Two different types of design roadmaps—simplified and detailed—were created in parallel to support different levels of conversations under a collective shared project vision. The simplified design roadmaps were beneficial for glancing at high-level experience themes and core features (depicted on the y-axis), and anticipating design concepts over time (x-axis). The detailed design roadmaps allowed practitioners to have richer communication, as they include detailed project descriptions such as lower-level experience themes and the types of form factors (y-axis) that represent those themes over the long-term span of the project (x-axis).

Postinterviews With Design Project Leads. After the completion of the design roadmapping process and the transfer of the tangible and intangible deliverables from the Silicon Valley team to the headquarters, follow-up interviews with each of the three project leads were conducted to discuss the benefits and drawbacks of the design roadmapping implementation. One benefit frequently mentioned by the project leads was having a wide-open roadmap layout that enabled them to explore without imposing technical constraints early in the planning stages—a stark contrast to how technology roadmaps were created and maintained. One participant comments:

"It really worked well. I mean the way [the template of] the Design Roadmap was loosely defined at the beginning, then incorporated frameworks and concepts from our users' perspectives, and then guided us to apply new technologies to help us achieve user experiences [that we aim to create in the future] worked great."

This highlights the challenge of traditional roadmapping, often described as "a plan not followed." One of opportunities of design roadmapping, thus, is to make the process more agile and iterative without requiring concrete linear future predictions [15,18]. Another participant comments:

"As [I am] a project lead [and a user experience designer], it was my first experience of [creating] a Design Roadmap during my decade-long career. It was useful as we started with a design perspective, [iterated on] key opportunity spaces, then looked into [associating] different technologies at micro levels."

Throughout the phases, the high-level experiences were kept the same and the associated subexperiences evolved gradually, whereas the technologies and features were not considered until these specific experiences were clearly defined. This result fulfills the experience-driven design roadmapping framework promulgated by Kim et al. [18].

Findings

Our case study provides insight into the important transition that companies are making as they move from being largely technology-driven to being more customer- or design-driven. It shows how a company can lay out a plan to develop user experiences over time, not just focus on a single experience in the present. It shows how the company might weigh choices between user needs (design principles) and technological innovation. Here, we highlight some key findings from our research.

The Effort to Move From a Technology-Driven to a Design-Driven Approach. An analysis of the choice of technologies in the projects represented here suggests that there is still room for more customer-focused design work. Of the total number of technologies identified by the project leads on the three projects examined, a majority (58%) were technologies concerned with input sensing, that is, they support data gathering from users or other devices to the display without user interventions. Only 24% of technologies were aimed at benefits that directly support the users' tangible/intangible experience resulting from the display (Table 8). The definition of each term in Table 8 is provided below:

- input: technologies that support data gathering from users or other devices to the display
- transition: technologies that support information transition between input and output in either direction
- output: technologies that support users in experiencing intangible/tangible benefits from display
- display: technologies that are solely related to display
- storage: technologies related to data storage either on the device or the cloud
- unique sales point: A marketing term not related to any of categories above that means a compelling feature that attract users to adopt a product

Table 8 Breakdown of technologies chosen by project leads by application area (the example of the illustration between input and output of technology flow can be found in Appendix B)

	Project P	Project W	Project M	Sum (%)
Input	24	17	7	48 (58)
Transition	2	0	2	4 (5)
Output	10	2	8	20 (24)
Artifact	1	1	0	2 (2)
Storage	1	0	3	4 (5)
Unique sale point	1	1	3	5 (6)
Sum (%)	39 (47)	21 (25)	23 (28)	83 (100)

Beckman and Barry [13] argue that high-tech companies tend to be driven by technology more than by user needs. In our observation, while teams in our case study aspired to be "experience-driven," when they started making critical decisions on the project they tended to become more "technology-driven." They became overly focused on how to bring technologies on hand to create design concepts without knowing what benefit the technology might provide for customers.

Planning User Experiences Over Time. Among the three design projects analyzed in our case study, we found a clear pattern in how the level of experience evolved through each phase of the design roadmapping process. When it came to envisioning the next user experience, the most common pattern we found was to move the follow-on experience one level ahead of the previous phase. The most common terminologies used among project members included verbs such as *enhanced*, *improved*, *enriched*, or *increased* to articulate the level of experience they wished to create in the next development phase. For instance, for project W (Table 7), the level of experience in the context of the connection theme evolved from open connections (short-term) to enriched connections (midterm), and then to seamless connections in the long-term.

Once the desired level of experience was clearly defined, technologies were identified to support that experience. A description of each technology was defined in project-specific language to extract core user experience levels for short-, medium-, and long-term. We observed that design roadmapping implementation encourages the teams to change their convention for considering possible technologies. Technological feasibility was not even considered unless desired levels of user experience were fully defined. In project W, core features were discussed as embedded sensors (short-term), direct gaze (midterm), and connected mobile sensors (long-term) only after their respective levels of experience were defined. This provided a means to actively define the experience levels to be achieved in future product releases.

Weighing Conflicts Between Design Principles and Technology Innovation. The mapping of design principles against a list of technologies was crucial, and many contradictions were found. Knowledge of the feasibility of a technology considerably influenced decisions about the level of experience planned in each phase. For instance, even though the project teams identified strong, compelling new concepts to develop, some of the required technologies would not be available in the short- or midterm phases. As it was critical to decide in which phases (short-, medium-, and long-term) the technologies under consideration should be placed, team members prioritized which technologies should be evaluated first. These processes entailed intervention by researchers to guide intensive discussion to align defined design principles with appropriate technologies. In many cases, a project that scored high against technology innovation criteria would score low on design principles and vice versa. The three design projects in Table 9 illustrate levels of technological innovation in each project measured by project members. From this comparison table, project P had the lowest technological innovation levels compared to the other two projects, while its score on design principles (Table 6) was the highest. For project P, most of the necessary technologies were available off-the-shelf, and thus could be implemented in existing devices. However, projects W and M required extensive development of innovative technologies such as depth-cameras and advanced image-capturing techniques that have not been examined yet.

Table 9 Level of technical innovation required for development (low, medium, and high)

	Project P	Project W	Project M
3D parallax display—display technology	—	High	—
Image capturing technology	—	High	High
Multiscreen synchronization	Low	Medium	—
User face detection	—	Medium	Medium
Multiscreen UI	Medium	Low	—
Touch gestures interaction	Medium	Medium	—
Air gestures recognition	—	Low	Low
Object recognition	Medium	Medium	Medium
Human buddy skeleton extraction and motion tracking	—	—	High

In making tradeoffs between technology choice and user experience design, two criteria arose as particularly important in our case study: acuteness of pain points and expected frequency of defined user experience:

(1) Acuteness of pain points
A concept will not be well received by users unless it can solve acute pain points, regardless of the level of technology innovation. If there are effective available solutions, users will choose them; only extreme or lead users will be willing to risk purchasing and learning to use innovative technologies [22]. For example, project M was considered an interesting concept with high scores for technology innovation, but not one that solved crucial pain points for users. Thus, project M received low scores against the design principle criteria.

(2) Expected frequency of defined user experience
All teams considered the frequency of the target user experience to be important. User testing on concept prototypes was used to evaluate the most frequently used interactions. The teams concluded that the motivation to use a solution as part of their daily routine provided evidence of the most frequently used and engaging user experiences. One respondent noted: "How often the product will be used is very important. Think about the toothbrush test. What is the point to create a product people would use less than twice a day?"

Lessons Learned From the Application of Design Roadmapping in a Large Organization. In an organization where two distinct groups collaborate—a headquarters in Asia and its innovation lab in Silicon Valley—the design roadmapping process facilitated better communication and decision-making processes between them. Early product concepts initiated in Silicon Valley were delivered to headquarters in Asia to be considered for product line-ups and roadmaps in commercialization strategies. Deliverables from Silicon Valley were sent in various formats, e.g., oral presentations, reports, videos, prototypes, and in-person demos. Interviews with internal stakeholders revealed that improvements in internal communications were crucial to the success of the design roadmapping process. Members had different perspectives and expectations of their projects and often deliverables were unclear in the past.

There were sometimes significant gaps between the two parties in defining the final goals of the projects and the level of final prototype completeness. These communication gaps were similar to those found between interaction designers and human–computer interaction practitioners in the HCI research field [21].

Another interesting observation was that prototype demonstrations were inefficient, as the two parties did not share a clear idea of the product concept within the limited range of remote communications deployed. Often the technology-driven thinking preferred by headquarters limited innovation team members' perspectives and creativity. Creating design roadmaps increased the engagement of representatives from both sides early in the planning process. This observation demonstrates that a key benefit of roadmapping is to improve the internal communication among diverse stakeholders within a company as well as external communication with outside collaborators such as suppliers, partners, and vendors [18].

In many contexts, the design roadmaps initiated in this group promoted better communication by conveying a concept as not only a form of the physical prototype but also an intangible visual canvas that showed both current and anticipated designs, and core experiences and technologies for future lineups. In addition, the design team's prioritization of key projects via the design roadmapping process greatly influenced corporate-level decisions for strategic design concepts, which drive funding for future evaluation.

As a result of the design roadmap-based decisions, the company further developed the project P concept, which had the highest score on design principles. The design roadmapping process led to the launch of a common household product the following year (Spring 2016) with enhanced functionality to improve family connections and engagement experiences [23]. The main goal of this project—"reflecting the flowing stream of everyday life to strengthen family connections and shared identity"—remained the same as it was defined in their design roadmap. This example illustrates the benefits for design roadmapping in strategic planning for high-tech products.

Limitations

The main focus of this research was to complete a concrete case study over a long period of time where an interdisciplinary team collaborates remotely with internal stakeholders. An obvious limitation of our work is that design roadmaps by nature work with sensitive intellectual property; thus, confidentiality agreements deter us from presenting more specific results.

Specific results, however, would not be replicable across organizations, as the nature of the experiences and technologies involved would by definition differ. The details on any given design roadmap will vary based on a company's organizational conditions, interests, goals, objectives, and available resources. However, we expect that organizations with similar structures (e.g., remote strategic planning, design, and product development functions) can derive benefits similar to those documented here.

Conclusion

This case study illustrates the use of our design roadmapping framework as a method to enhance early-stage design and project selection processes driven by "design principles" criteria, that is, by the end user's experience. The design roadmapping process augmented the existing design process of a global high-tech company's innovation centers located in Silicon Valley, with corporate stakeholders located in Asia. Using in-depth interviews and long-term observations of a global company that develops high-tech consumer products, this case study encompassed the five-step process of design roadmapping, providing useful illustrations and examples.

The design roadmapping process assists project prioritization and selection. Mapping the design elements to technologies—as an effort to integrate customer and user needs with technology choices—was a crucial part of the process that led to an in-depth discussion of tradeoffs among participating team members. The design roadmapping process encouraged the teams to focus on experience-driven planning early in the design process, thereby increasing the likelihood of a product desired by customers. It increased the engagement of designers early in the planning process so that they could take more ownership in decision-making. Finally, the design roadmaps initiated in this case study promoted active communication among stakeholders by exchanging design ideas—about not only the current concept and its physical prototype but also about future design concepts as well.

Future Research

This paper describes the first application of design roadmapping in a high-tech company, with a focus on project selection in early-stage planning in new product development. It embeds user-experience-driven design roadmapping by offering metrics to compare design principles against technical feasibility. In future research, we will continue to work on the development and application of design roadmapping, driven by design experience criteria applied to new applications for products, services, and system design. We aim to create a generalizable design roadmapping framework that would be applicable to a wide variety of company settings. The authors are developing both software and tangible tools for using design roadmapping in product development teams.

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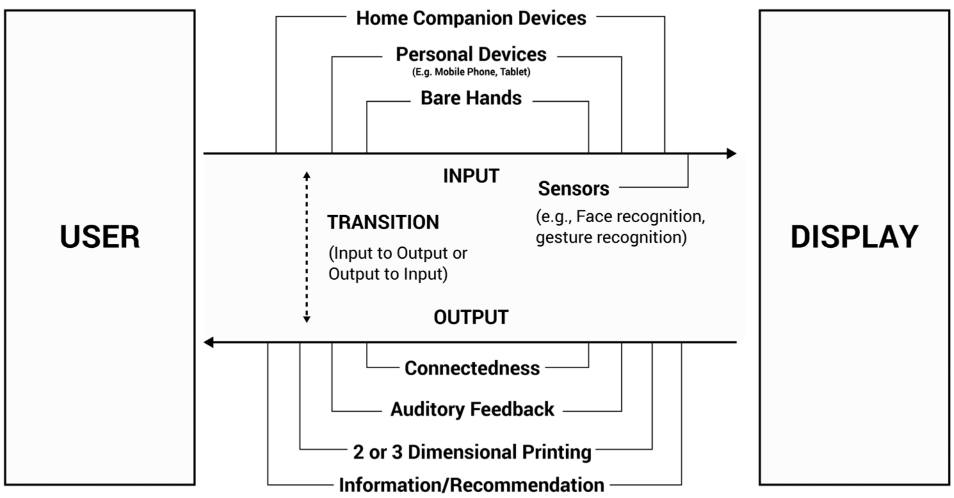
Appendix A: Map Projects to Design Principles and User Experience (UX) Themes

Source	No.	User experience theme	Design principles criteria	Project P	Project W	Project M
Expert interview (2014)	1	Analog–digital open flow	Co-existence/mixture/transition (input and output, analog and digital, inside and outside, and internal and external)	4	5	2
	2	Hybridization	Co-existence/mixture/transition (input and output, analog and digital, inside and outside, and internal and external)	4	5	3
	3	Authenticity	Genuineness	3	5	3
	4	Humanization	Genuineness	5	3	2
	5	Simplicity	Minimal interaction	5	5	3
	6	Ambient atmosphere	Minimal interaction	5	4	3
	7	Me-powered	Empowered data	5	3	2
	8	Meaningful data	Empowered data	5	2	3
	9	Tactile interaction	Physical representation	4	5	2
	10	Tweak reality	Technology-empowered experience	2	1	1
	11	Neo-cyberpunk	Technology-empowered experience	3	4	3
UX report (2014)	1	Mobile device diversity and management	Mobile experience	5	3	2
	2	Mobile apps and applications	Mobile experience	2	3	2
	3	IoT	Mobile experience	4	3	2
	4	Hybrid cloud and IT as service broker	Co-existence/mixture/transition (personal cloud and public cloud)	4	2	2
	5	Cloud/client architecture	Data storage	4	3	3
	6	The era of personal cloud	Technology-empowered experience	4	3	1
	7	S/W-defined anything	S/W-based device control	3	4	2
	8	Web-scale IT	Data storage	4	2	1
	9	Smart machines	Technology-empowered experience	5	5	2
	10	3D printing	Co-existence/mixture/transition (input and output; analog and digital)	4	1	0
User research (2014)	1	Morning rituals	Anticipatory computing	5	3	1
	2	Smart watches/wearable devices	Technology-empowered experience	3	1	0
	3	Anticipatory decision/automation	Empowered data	5	3	0
	4	Sensors everywhere could mean privacy nowhere	Privacy/security	2	4	0
	5	Anticipatory sensor-embedded	Empowered data	5	4	0

Continued

Source	No.	User experience theme	Design principles criteria	Project P	Project W	Project M
		technologies				
	6	—	Communication network	5	4	3
Intel trend report (2014)	1	Shared awareness	Empowered data/genuineness	5	4	2
	2	Programmable lifestyle	S/W-based device control	4	3	2
	3	Open sources access	Empowered data	4	3	1
	4	Behavioral nudge	Empowered data	3	5	0
	5	Emotional response	Physical representation/ genuineness	3	5	1
	6	Contextual experience	Anticipatory computing	5	5	1
	7	Adaptive machines	Empowered data (connected)	5	4	1
	8	Distributed intelligence	Empowered data (connected)	5	5	2
	9	Environmental whisper	Empowered data (connected)	4	4	1
	10	Anticipated (orchestrated) action	Anticipatory computing	4	5	1
Parenting in the age of digital technology (2013)	1	TV as educational tool	Genuineness/physical representation	5	2	4
	2	TV as educational tool/positive effect on children's reading	Technology-empowered experience	4	2	5
	3	Coviewing on TV more, mobile less	Communication network, parental co-engagement (family activity)	5	2	5
	4	Low-income/less highly educated parents are more media centric	Technology-empowered experience	5	2	4
	5	Opportunities on other parental concerns	Empowered data	5	2	3
	6	TV as a center of media environment	Communication network	5	4	3
	7	Activity recognition	Technology-empowered experience	5	5	3
	8	Parents' sources of advice about media content	Communication network	5	5	3
Total				190	157	90

Appendix B: Illustration of Intelligent Display Ecosystem: A Connection Between Users and Artifacts by Technology Categorization



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