A Media Architecture Design Space: The MAB 2012–2018 Nominees

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We suggest organizing a collection of media architecture instances around the design space they populate. We offer a process for identifying the constituent parts of the media architecture installations, together with a tool that supports the process, and the subsequent exploration of the design space. In the main part of this paper we use this process to construct the design space occupied by the 54 nominees for awards at the media architecture biennales in 2012, 2014, 2016, and 2018, and we address how the process of decomposing the collection of media architecture instances and constructing the design space is the first step of the knowledge acquisition process; this is followed by an analysis of the MAB 2012–2018 design space. The process starts with a basic quantitative analysis, followed by a closer investigation of two-dimensional subspaces. Before presenting our conclusion, we address the possibility of using the design space as a generative tool.

CCS Concepts: • **Human-centered computing** → **Interaction design**.

Additional Key Words and Phrases: Design space, Collection of designs, Creativity, Inspiration, Design tools

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1 INTRODUCTION

The discipline of media architecture frequently compiles collections of media architecture instances for both research and industry. The Ag4 media architecture company started to develop the idea of media façades as early as 1992, and has published a book that presents 15 media façades organized around three themes: Interactive Programming, Auto-active programming, and Reactive programming [1]. Typically, each media façade is presented with 15 lines of text (in English, German, French, Italian, and Spanish) and up 10 images, and states the title, location, architect's name, and year of realization. Similar to the Ag4 collection, Hank Haeusler's book, Media facades: History, Technology, Content, is a catalogue of 36 media façades organized in six categories: mechanical, projector, illuminant, display, customized technology, and voxel façade technology [13]. Each of the six categories is presented in an introductory section, and illustrated with four to eleven media-façade projects. As in the Ag4 compilation, each project is illustrated with photos and metadata such as location, year of completion, content designer, and developer. A separate chapter introduces three kinds of media content (prerecorded content, live media content, and interactive media content) illustrated with a few media façade instances. In 2012, in the same avedition book series, Hank Haeusler, Martin Tomitsch, and Gernot Tscherteu provided an updated collection [14]. The main part of the book presents 33 media-façade projects, organized around geographic location and continent. The second part presents four new trends, including Green media façades, and illustrates each trend with two media façade cases.

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Christopher Alexander and his colleagues have developed a pattern language for architecture that is based on research into several hundred years of architectural history, and is a formal system for organizing knowledge about architecture cases [2]. Each pattern provides knowledge concerning an architectural problem or aspect, for instance "Entrance," and illustrates possible solutions and an example. The field of design also has a strong tradition of collecting and describing design examples as sources of knowledge. A particularly common format is the annotated portfolio organized around design artifacts, an approach for communicating design knowledge to both researchers and design practitioners [12]. More generally, it is well-established that earlier design cases are an important resource in design and architecture, most famously conceptualized by D. Schön as the designer's repertoire [30].

In this paper we suggest organizing a collection of media architecture instances around the design space they populate - 'design space' in a metaphorical sense, in contrast to the physical space where the design process is unfolding. We demonstrate how the deconstruction of media architecture instances enables us to construct the design space they populate. In pursuance of this, we start by mapping the varied ways in which design space has been conceptualized, which form the basis for arguing for an understanding of a design space as consisting of a number of aspects of design, each comprising a set of options. Next, we present a process for decomposing the media architecture cases, together with a tool that supports the process, and the subsequent exploration of the design space. In the main part of this paper we use this process to construct the design space occupied by the 54 nominees for awards at the media architecture biennales in 2012, 2014, 2016, and 2018, and we address how the process of decomposing the collection of media architecture instances and constructing the design space is the first step of the knowledge acquisition process; this is followed by an analysis of the MAB 2012–2018 design space. The process starts with a basic quantitative analysis, followed by a closer investigation of two-dimensional subspaces. Before presenting our conclusion, we address the possibility of using the design space as a generative tool in future design processes.

2 DESIGN SPACE

The term "design space" may refer to the physical space within which design activities take place [28] however, it is far more common for design spaces to be metaphorical, [4, 5, 11, 12, 21], which is the way this term is used in this paper. Metaphor is a way of understanding one domain in terms of another [20]; in the case of the design space metaphor, this essentially means understanding the organization of the elements of design knowledge in terms of concepts that define physical spaces, for instance, dimensions, position, and area.

The scope of design space ranges from the design space of a particular kind of technologies (input devices [5]), interaction techniques [3], and shape-changing interfaces [27], to the design space of a collection of designs, ideas, and sketches [12], and design spaces as all accumulated knowledge at a particular point in time [18]. Moreover, a design space may be represented in various ways, including as a Cartesian space [31], a networked graph [32], and a conceptual space [4, 7].

In this paper we present the design space of a collection of design examples as a conceptual design space organized as a number of dimensions or aspects, each associated with a set of values or options. To operationalize the design space, we, in line with Dove, Halskov, and Hansen[7], represent the design space as a design space schema. Table 1 illustrates this idea, using the display element of media architecture as an example. For each aspect (Media Format, Pixel Shape, and Color Range) in the top row, the corresponding options are listed below ; for Media Format, these options are Text, Images, Video, and Abstract Graphics.

Media Format	Pixel Shape	Color Range
Text	Rectangular	Monochrome
Images	*Round*	Duochrome
Video	3D Polygonal	*RGB*
Abstract Graphic	3D Spherical	

Table 1. A design space schema.

As an example, we have identified the location of one of the MAB nominees—The Danish Expo Pavilion—in the design space, by italicizing the relevant options in Table 1, indicating that the Pixels were Round, the Media Format were Video and Abstract Graphics, using the RGB Color Range.

The conceptual design space represented by design space schemas is the foundation of the design space analysis approach, which we present in the next section.

3 THE DESIGN SPACE TOOL AND PROCESS

In a previous paper, we presented a three-step process for mapping the design space of a collection of objects:

(1) Select the design exemplars
(2) Deconstruct the design objects and constructing the design space
(3) Explore the newly constructed design space

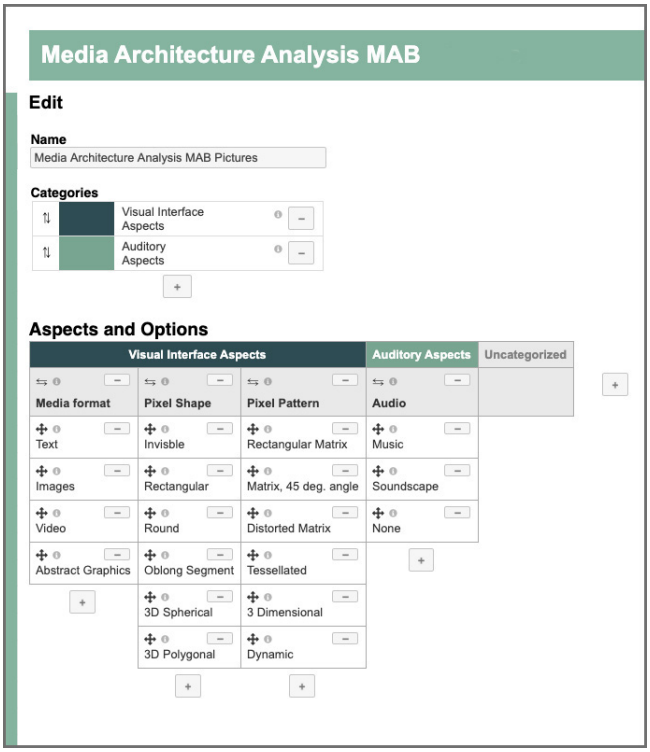

Fig. 1. The design space tool's edit mode.

Step one consists of delimitating the collection of design examples, which in this study meant the media architecture cases that have been nominated for an award at one of the media architecture biennales in the 2012–2018 period. Of the 57 nominees we decided to exclude three, because they did not have a physical manifestation beyond a mobile phone interface (CyclePhilly and Digital Matatus) or a web interface (Our Meeting Places). In addition to being clearly delineated, the MAB nominees had the advantage of being well-documented on the MAB websites with text, images, videos, and links to additional information. Hence, despite the large size of the collection, the collection is only a small sub-set of the hundreds media architecture installations developed during more than half a century.

The second step, decomposing the design objects and constructing the design space, starts with browsing the collection of media architecture cases, to initially identify core aspects of a media architecture installation. As with any analytical process, the starting point is not a tabula rasa. The process is based on knowledge about interactive technologies, media formats, and aspects unique to media architecture, for instance, ways of integrating the media technology into physical architecture, and pixel-related aspects of media architecture [10]. The process is a highly iterative activity of constructing the design space schema and testing the schema against the examples by positioning them in the design space.

Once the design space has been constructed, it is time to move to the last step, exploring the design space, which consists of identifying patterns, highly as well as sparsely populated area of design space, and so on, to which we return in greater detail in the analysis section.

To support the foregoing three-step process our interaction design lab, CAVI [16], have developed a web-based tool: The Design Space Tool, see video at www.cavi.au.dk/projects/cibis/research-tools. The tool's interface has two main parts, Edit and Search, each organized around a design space schema that represents the design space. In edit mode the user may develop aspects and options associated with each aspect. Aspects may be organized into categories, and both aspects and options may be deleted. Options maybe moved from one aspect to another (see Figure 1).

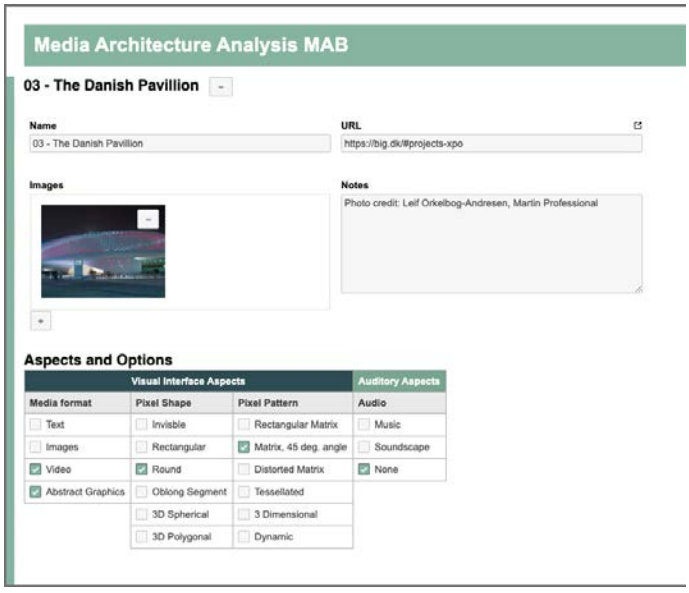

Fig. 2. Entering a design instance.

Design examples are added by uploading one or more images and adding a URL to link to information about the design example. Also, a free-text note field is available for addition information. Most importantly, the user may indicate the location of each design example in the design space by checking the options relevant to the example (see Figure 2). As mentioned, the tool is web-based, and each design space schema may be shared in both read-only mode and in edit mode.

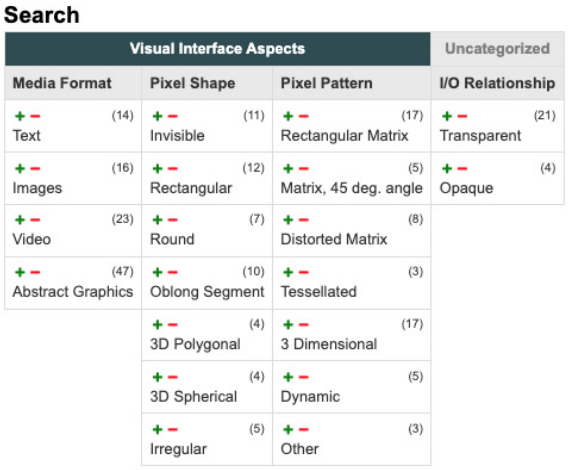

Fig. 3. The design space tool's search mode.

In search mode, Figure 3, the user may explore the design space by filtering it though combinations of options: clicking the "+" sign beside an option includes all design examples that share that particular option, and clicking the " — " sign includes all design examples that do not share that particular option. Option selection and deselection may be combined across aspect–option sets. The examples filtered in this way appear as thumbnails below the design space schema, and clicking the name associated with the thumbnail provides access to the full information about the design example. Moreover, by selecting two aspects in the drop-down menus of the 2D Subspaces section of the tool, the tool displays the corresponding 2-dimensional subspace, see Figure 4.

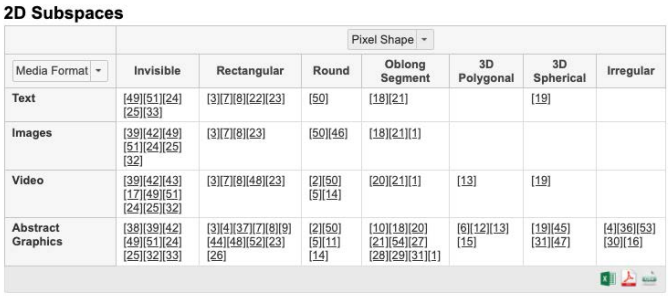

Fig. 4. The 2D Subspaces mode of the design space tool.

2012	2014	2016	2018
1. Galleria Centercity	12. Harpa	21.LED Frieze	41. MUURmelaar
2. Kunsthaus Graz	13. C4 Media Facade	22. Train Station Falkenberg	42. Kipnes Lantern
5. Danish EXPO Pavilion	14. Energy Tower Facade		43. Theatre of experience
	18. DIA Lights		
3. Star Place	18. DIA Lights	23. Klubhaus St. Pauli	38. Hyundai Pavilion
6. Crystal Mesh	19. Hanjie Wanda Square	24. LAX - Tom Bradley	39. Terrell Place
	20. Mondeal Square	25. Morgan Stanley	40. Firefly
4. 3D Bridge		26. In the Air, Tonight	32. Chave do Centro
7. Blinkenlights		27. Sentiment Cocoon	33. Digital Calligraffiti
8. Marnix		28. Le circuit de Bachelard	34. Arena
9. Digital Fountain	15. Spine	29. Star	36. HALO36
10. GS Caltex Pavilion	16. Light Barrier	30. Waterlicht	37. Merck Light Cloud
11. Silo 468	17. Human Being	31. Field of Light	35. Where do we go from here?
52. Living Sculpture	46. Megafaces Pavilion	44. City Light Orchestra	48. One Shenzhen Bay
53. Lotus Dome	50. Discovery Wall	45. Spaxels	49. Archive Dreaming
54. One Ocean	51. Birloki	47. Fluidic	

Table 2. Overview of the MAB media architecture collection by year. Divided by horizontal lines according to the nomination categories: Animated Architecture, Money Architecture, Participatory and Urban Interaction, Spatial Media Art, and Future Trends.

4 THE DESIGN SPACE

In the previous section we presented our design space analysis approach, which we have applied to the selection of 2012–2018 MAB media architecture nominees, which we present in this section.

The design space of the collection of 54 media architecture cases is organized around six categories of aspects: MAB Information, Location, Architectural Aspects, Interaction Aspect, Visual Interface Aspects, and Auditory Aspects. The design space is available at www.tinyurl.com/y8sfnzaa.

The MAB Information is metadata about cases, rather than a design space aspect, and consists of the MAB Category with options that correspond to the five award categories, MAB Year, and Year of Construction. Table 2 provides an overview of the 54 media architecture cases with respect to nomination category and year.

Geographic Region	Area Type
Africa (1)	Exposition Area (6)
Asia (15)	City Center (39)
Europe (30)	City Outskirts (39)
North America (9)	Park (2)
South America (1)	Industrial Area (1)
Oceania (1)	

Table 3. Location aspects.

The second category of aspects, Location, consists of only two aspects, Geographic Region and Area Type, with the option of five kinds of urban areas (Table 3).

Three of the Architectural aspects are straightforward (Table 4). The Duration aspect–option set captures whether the media architecture project is permanent or temporary, and the options of In- or Outdoor aspect distinguish between

Duration	In- or Outdoor	Coverage	Physical Relationship	Abstract Relationship
Permanent (29)	Outdoor (42)	Entire Structure (25)	Inseparable (14)	Yes (23)
Temporary (25)	Indoor (13)	Segment (19)	Integrated (20)	No (25)
			Projection (7)	
			Installation (17)	

Table 4. Architectural aspects.

the media or digital element being inside the building or on the façade. The two options of Coverage aspect capture the extent of to which the media cover the building.

The Physical Relationship aspect is more complex, and addresses how the media architecture project relates to the physical architecture, in terms of physical integration. The four options are:

- Inseparable refers to display technology that is integrated to such a degree that it cannot meaningfully be separated from the existing architecture.
- Integrated refers to display technology that has been physically integrated into existing architecture.
- Projection also includes laser beams.
- Installation refers to a structure that is freestanding and has no accessible internal space.

The Abstract Relationship aspect addresses whether or not the media architecture case has an abstract, conceptual relationship to existing architecture. An example would be a media-architecture façade that mirrors activities inside the building.

Interactivity	Input Source	User Interaction	Temporal Relationship	I/O Relationship
Interactive (26)	Users (17)	User Application (7)	Immediate (21)	Transparent (21)
Not Interactive (28)	Sensors (10)	Website (2)	Delayed (8)	Opaque (4)
	Data Feed (6)	Mobile Phone (4)		
		Tangible (5)		
		Bodily (6)		

Table 5. Interaction aspects.

The Interaction Aspects category consists of five aspects (Table 5). As the most basic aspect, Interactivity addresses whether the project is Interactive or Not Interactive. The Input Source aspect has three options:

- Users refers to input originating from the users, both in the sense of direct, deliberate interaction from users, and in the sense of using sensors to monitor users for input.
- Sensors refers to automated input from the local environment, such as sensors that monitor local weather conditions.
- Data Feed refers to automated input from an external data source, such as a Twitter feed or a database with stock prices.

The User Interaction aspect is a refinement of the User option, and addresses the mode of interaction:

- User Application refers to input that is sent, and in some cases also created, through a user-dedicated application stored and executed on the user's local device.

- Website refers to input that is sent, and in some cases also created, through a user-dedicated website.
- Mobile Phone refers to input that is sent using the existing mobile phone signal system, for instance, allowing users to send SMS messages to control the content displayed on the media architecture.
- Tangible Interaction refers to physical input through physical objects near or inside media architecture, including touching the media architecture.
- Bodily refers to interaction without the use of any interaction devise, for instance through gestures or other kinds of bodily movement.

The Temporal Relationship aspect addresses the temporal relationship that governs User Interaction, in terms of the time lapse between user input and the response from the media architecture.The I/O Relationship aspect addresses how transparent the relationship between input (from users, environmental sensors, or external information feeds) and output (displayed). In other words, it addresses the ability of an ordinary user, with no particular insider information, to determine how the media architecture reacts to input. The associated options are:

- Transparent refers to a project where users can identify and understand the relationship between input and output.
- Opaque refers to a project where users may identify a relationship between input and output, but the relationship is not readily discernible.

The Visual interface aspect addresses two broad visual aspects (Media Format and Color Range) and a set of pixel-related aspects unique to media architecture. Media Format concerns the media type, and includes four options: Text, Images, Video, and Abstract Graphics. The Color Range aspect includes three basic options: Monochrome, Duochrome and RGB (Table 6).

Media Format	Color Range	Pixel Shape	Pixel Pattern	Pixel Spacing
Text (14)	Monochrome (21)	Invisible (11)	Rectangular Matrix (17)	Varied (16)
Images (16)	Duochrome (1)	Rectangular (12)	Matrix, 45o Angle (5)	< Pixel Size (25)
Video (22)	RGB (30)	Round (7)	Distorted Matrix (8)	Pixel Size (7)
Abstract Graphic (47)		Oblong Segment (10)	Tessellated (3)	> Pixel Size (13)
		3D Polygonal (4)	3 Dimensional (17)	
		3D Spherical (4)	Dynamic (5)	
		Irregular (5)	Other (3)	

Table 6. Visual aspects.

The category of visual aspects also includes three aspects related to pixels: Pixel Shape, which addresses the shape of the pixels that make up the display of the visual interface, Pixel Pattern, which addresses the arrangement of the pixels in the display, and Pixel Spacing, which addresses the spaces between the pixels in the display.

Pixel Shape included a set of options unique to media architecture:

- Invisible refers to pixels that are invisible to the naked eye.
- Rectangular refers to pixels that are rectangular, including square.
- Round refers to pixels that are round or nearly round.
- Oblong Segment refers to pixels that are oblong and part of a larger pixel structure—for instance, a pole consisting of segments that function independently as pixels.
- 3D Polygonal refers to pixels that have a three-dimensional polygonal shape—for instance, pyramidal.

- 3D Spherical refers to pixels that have a three-dimensional spherical, or nearly spherical, shape—such as a traditional light bulb.
- Irregular refers to shapes that do not fit any of the other options.

Pixel Patterns also includes a set of visual options unique to media architecture:

- Rectangular Matrix refers to a horizontally and vertically aligned matrix of pixels.
- Matrix, 45-degree Angle refers to a rectangular matrix of pixels shifted 45 degrees from the horizontal.
- Distorted Rectangular Matrix refers to a horizontally and vertically aligned matrix of pixels that has been distorted.
- Tessellated refers to a non-rectangular and tessellated pixel pattern.
- 3 Dimensional refers to pixels that are organized in three-dimensional space
- Dynamic refers to pixel patterns that dynamically change.
- Other refers to patterns that do not fit any of the other options.

Pixel Spacing includes the following set of options:

- Varied refers to a display in which the distance between pixels varies across the display.
- < Pixel Size refers to a display in which the distance between pixels is smaller than the pixel size.
- Pixel Size refers to a display in which the distance between pixels is roughly equal to the pixel size.
- > Pixel Size refers to a display in which the distance between pixels is greater than the pixel size.

Audio
Music (4)
Soundscape (6)
Sound Effects (2)
Speak (1)
None (43)

Table 7. Auditory aspects.

The last category of options includes only one aspect, Audio, which, in addition to None (no audio output), offers four options: Music, Soundscape, Sound Effects, and Speak (Table 7).

5 REFLECTIONS ON THE CONSTRUCTION OF THE DESIGN SPACE

The decomposition of the collection of media architecture instances and the construction of the design space presented in section 4 is the first step of the knowledge acquisition process. But how did the conceptual design space schema emerge from the collection of media architecture cases? And could the final result, in Table 3 to Table 7 have been different? The latter question is easy to answer with a "Yes," and the argument is part of addressing the first, and much more complex question.

First, it is important to note that the process of defining the design space presented in the previous section was a highly iterative process that involved going back and forth between the collection of media architecture cases and the design space. For instance, the Speak option was included late in the process, when the 2018 case Arena was encountered.

5.1 Granularity of options

In the final representation of the design space we distinguish among three kinds of color options, which reflects the general and recurrent choices with respect to how nuanced a set of options should be. For the color aspect we did consider including a set of primary colors (red, green, and blue), but since none of the cases was based on these, we decided against this. Similarly, it could be argued that the Duochrome option should have been omitted, since only one instance uses the Duochrome option (Digital Calligraffiti), and this is a special case of RGB. And along the same lines, it is worth considering replacing the Mobile Phone option with the broader option of "Hand-held Device," which would include mobile phones, tablets, and similar devices. In the current version of the design space, the User Interaction in the case of Archive Dreaming is Tangible, though tablet-based is more precise.

Several of the options could have been divided into more specific options, for instance, Mobile Phone Interaction includes both text messaging and blue-tooth interaction, and for the Sensor option we do not distinguish among the many sensors available. Similarly, Gesture was considered a kind of User Interaction, but a more general term (Bodily) was chosen. A general consideration with respect to the granularity of the options has been that we strove to avoid options present in only one instance, on the one hand, and avoid any option that is relevant to almost all instances.

The most common Area Type is City Center (39 case), whereas City Outskirts and Industrial Area are represented by just three cases and one case, respectively, and for that reason, we considered merging City Outskirts and Industrial Area. City Center includes a large number of cases, and could have been refined into a set of City Center areas such as city square, main street, and business district.

5.2 Redefining options

Several of the option sets were redefined during the coding process. A prominent example is the Pixel Shape, which, early in the process, included Square Pixel, composed of tiny, invisible pixels, large square pixels, and a Rectangular option. In an effort to better define the Pixel Shape options, we decided to have an Invisible option and to redefine the Rectangular option to include visible square pixels. As mentioned earlier, Pixel Shape is one of the unique aspects of media architecture, and it comes as no surprise that the set of options was revised several times during the process. At one point the option set included an "Other" option, but since we preferred to avoid generic option labels, Other was renamed Irregular. In general, we strove to avoid generic categories such as Other and None, and sought distinct names, for instance, the None option of Physical Relationship was re-labelled Installation. We also avoided general terms such as "type of architecture," which early in the coding process included a set of options that was divided into the In- or Outdoor and Physical Relationship aspects.

The Physical Relationship was the most challenging aspect to define, and went through several iterations of tentative aspect option sets (e.g. Embedded, Addition, and Distinct), which were tested against the collection of cases, to eventually become the four Physical Relationship options in the final version (see Table 4). When an option was changed, all cases were revisited and checked with respect to the aspect in question.

One the practical side, several of the labels were shortened to fit a maximum of two lines in the table of the design space tool, and also to make the presentation of the design space schema fit this paper's page format. Names were shortened in several cases, for instance, External was omitted from External Data Feed, Mobile Phone Signal was shortened to Mobile Phone, Display Content was shortened to Content, and Physical Relationship to Existing Architecture was changed to Physical Relationship.

5.3 Developing the sets of aspects

Above, we addressed the granularity of a set of options, and defining the set of options associated with a single aspect, and we now turn to the complexity of defining a set of aspects, and the options associated with those aspects. This is illustrated by the way in which the interaction aspects were gradually refined throughout the process, from an initial distinction between Interactive and Not Interactive cases (see Interactivity in Table 5), to also including the Input Source aspect, which covers the kinds of input sources relevant to an Interactive case. Also, the Users option has been further refined by adding a User Interaction aspect with five options. All three option are positioned next to each other and in a left-to-right sequence that reflects the refinement described above, see Table 5.

5.4 Positioning the media architecture instances

Above, we addressed the process of defining the design space in terms of aspects and associated options. The other part of constructing the design space of the collections of MAB media architecture cases involves positioning each case in the design space. As mentioned earlier, the construction of the design space is based on information available on MAB websites as text, images, videos, and links to additional information, and identifying the options relevant to each case has generally been possible, though not always easy. But, despite the iterative process of defining the aspect–options sets and testing the design space schema against the collection of cases, we encountered borderline cases and other kinds of challenges. It should be noted that more than one option of an aspect may be relevant to a media architecture case, for instance, Digital Calligraffiti has been deployed Indoors and Outdoors, and Blinkenlights' Temporal Relationship is both "Immediate" (playing the game of Pong) and "Delayed" (submitting an animation through a user application).

5.5 Borderline cases

The most extreme borderline cases are the three that have no physical manifestation beyond a mobile phone interface, and are excluded from the design space (see The design space tool and process section).

"Interactive" is a well-established term, and worked well as a potential option for the Interactivity aspect, but we also encountered borderline cases, for instance, Chave do Centro, which provided the opportunity to submit proposals for images to be displayed, but since the images were not submitted and displayed in real time, we designated Chave do Centro as Not Interactive.

The Coverage aspect includes two options, Entire Structure and Segment, which has been a clear distinction in most cases, but we also encountered cases such as Blinkenlights, which covered an entire side of a building, but not the entire building, and for that reason we selected the Segment option for the Coverage aspect for Blinkenlights.

Some of the cases are clear-cut installations, such as Digital Fountain in a city square, but other cases are less straightforward, for instance, Spine, which is made of 20 one-cubic-meter cubes mounted in the ceiling of an abandoned factory building, which lies at the border between Integrated into a building and being an Installation.

As mentioned in section 5.1 several of the options could have been divided into more specific options, and as an example, the Installation aspect could have been split into two aspect, Installation and Integrated Installation.

5.6 Challenges

Pixel Shape is one unique aspect of media architecture, and presented particular challenges during the development of the design space. The 3D Bridge challenges the conventional understanding of what constitutes a pixel because

each bar may actually be considered a pixel, but the bars also form rectangles and cubes that function as pixels. But since the smallest unit is the individual bar, we selected the Oblong Segment as the Pixel Shape option. The Star media architecture, a similar case, was implemented by mounting LED strips to hundreds of meters of steel cable, and in a way the pixel shape is Invisible, but since each wire operates as a single pixel, the Pixel Shape is Oblong Segment.

Two aspects presented particular challenges: Abstract Relationship of the Architectural Aspects and I/O Relationship of the Interaction Aspects. The Abstract Relationship aspect addresses whether or not a media architecture case has an abstract, conceptual relationship to existing architecture. In some cases, the documentation of the case explicitly states that the media architecture relates directly to a building, as in the case of the Morgan Stanley headquarters at Times Square, which was designed with the intention of branding and promoting the company, by displaying stock index data, for example. In other cases, the relationship is apparent from the available images and video documentation, as in the case of the Danish EXPO Pavilion, which displayed an animation of the Danish flag. Other cases, such as Kunsthaus Graz – BIX, are subtler and harder to classify. In some cases, video documentation causes problems with respect to Audio, because it is not always possible to determine whether the sound in a video is part of the media architecture installation or background music, as in the case of Fluidic.

The I/O Relationship is tricky, since it addresses how media architecture is experienced by people facing it. Some of the cases are fairly easy to classify, for instance, MUURmelar, where movement along the façade immediately triggers a sound. Other are harder to classify, for instance, In The Air, Tonight, which displays the local wind speed and direction, but, we would argue, an empirical study is needed to determine whether people experience the relationship between visual displays and the wind. Similarly, in some cases Temporal Relationship may be hard to determine, based on the available documentation.

The borderline cases and challenges discussed above may sound problematic, but as we discuss at the end of this paper, they also offer opportunities for using the design space as a generative resource in the design of innovative kinds of media architecture.

5.7 Summary

The reflection on the process of construction the design space may summarized as the following set of guidelines and matters of attention:

(1) Avoid options present in only a single instance, and avoid options that is relevant to almost all instances.
(2) Find specific names for generic option labels like ‘other’ and ‘none’.
(3) The process of defining the aspect–options sets and testing the design space schema against the collection of cases is an iterative process.
(4) Pay special attention to borderline cases.
(5) If possible, consider to supplement available documentation with empirical studies.

6 ANALYSIS

In this section we explore two levels of complexity of the design space of the Media Architecture Biennale nominees. We start with a basic quantitative analysis of the profile of the design space with respect to selected key aspects. For the subsequent analysis we zoom out and explore two-dimensional subspaces of the design space.

6.1 Basic quantitative analysis

The design tool automatically calculates the number of design case examples that share each of the options associated with a design space aspect, and displays the number in parentheses beside the option (Table 3 to Table 7). It is important to note that not all aspect option sets are relevant to all cases. For instance, if a media architecture case is Not Interactive, the User Interaction aspect is, understandably, irrelevant. Nor are the options mutually exclusive: For instance, both the Projection and the Installation options of the Physical Relationship aspect may be relevant to an installation.

A basic quantitative analysis of the design space yields a number of key insights. With respect to Geographic Region, Europe and Asia stand out as the most common locations, with 30 and 15 cases, respectively. Also, it is remarkable that City Center is by far the most common Area Type, with 39 cases (Table 3).

A number of observations may be made regarding the Architectural aspects (Table 4). A basic finding related to Duration is that there are almost the same numbers of Permanent and Temporary cases, and it is perhaps no surprise that media architecture appears predominantly on the building exteriors. The Architectural aspect specific to media architecture is the Physical Relationship, and, as shown in Table 4, cases are distributed fairly evenly among the four options, Projection being the least common. The total number is greater than the total number of cases (54) because more than one Physical Relationship option may be relevant to a media architecture case: For instance, Light Barrier, which is based in crossing light beams in the air, is both an Installation and based on Projection technology.

The Interaction category includes five aspects, Interactivity being the most fundamental, as it distinguishes between Interactive and Not Interactive cases; there are slightly more Not Interactive ones (Table 5). With respect to Temporal Relationship the vast majority is Immediate responds (21), and Transparency (21) is the most common I/O Relationship.

The majority of the cases have Users as their Input Source (17), but Sensors (10) and Data Feed (6) are also common. The User Interaction aspect reveals a diverse set of modes (Table 5).

Media Format and Color Range are the two most general visual aspects (Table 6), and like other media, media architecture utilizes a range of Media Formats, Abstract Graphics being the most common one (47). The Color Range is predominantly RGB (30), and Monochrome is also common (21). The Duochrome option is relevant to only one case.

The pixel-related aspect is one of the areas of the design space where media architecture genuinely stands out with a large range of options unknown to conventional displays, though the conventional Invisible pixel occurs in 11 cases (see Table 6). Though the two-dimensional pixel is the most common Pixel Shape, there are interesting exceptions in terms of four instances that used the 3D Polygonal Pixel, and four that used the 3D Spherical Pixel. Similarly, we may note a variety of pixel patterns, including pixels that are distributed not only in two dimensions, but also three (17). One category that stands out is Dynamic, the option in which the pixels do not have a fixed position (5). The Pixel Spacing is also quite varied.

Remarkably, the final Aspect, Audio, is rarely used, and the Speak option is relevant to only one case.

6.2 Two-dimensional subspaces

In the previous section we applied a one-dimensional perspective to the design space, and in this section, we explore two-dimensional subspaces of the design space. Essentially, any combination of two aspects may be considered, and to illustrate the possibilities we first consider the subspace defined by the Media Format and User Interaction aspects. This subspace is illustrated in Table 8, with the Media Format as rows and User Interaction as columns, and the ID numbers of the cases (see Table 2) appear in each of the locations of the subspace in the corresponding cell in the table.

For instance, several cases (7 Blinkenlights, 8 Marnix, and 49 Archive Dreaming) share the combination of Text and User Application options, and only one case, 39 Terrell Place, is a Bodily Interaction with Images case.

	User Application	Website	Mobile Phone	Tangible	Bodily
Text	8, 49, 7	8	51, 18	33, 49	
Images	8, 49, 7	8	51, 18	49	39
Video	8, 48, 49, 7	8	51	49	39
Abstract Graphics	8, 26, 48, 52, 49, 28, 7	8, 26	51, 28, 18	27, 33, 10, 49	47, 53, 28, 15, 39

Table 8. The Media Format (rows) and the User Interaction (columns) subspace.

The representation of two-dimensional subspaces enables us to obtain deeper insights into the design space than a one-dimensional analysis provides. In the previous subsection we noted that Abstract Graphics is the most prevalent Media Format, and the two-dimensional subspace in Table 8 offers a more nuanced understanding of the design space, by revealing that the most common kinds of interaction to occur with Abstract Graphics are User Application, Tangible Interaction, and Bodily Interaction, whereas Web based and Mobile Phone interaction occur with Abstract Graphics rarer.

As mentioned earlier, the options an aspect comprises are not mutually exclusive: In other words, more than one option of an aspect may be relevant to a case, for instance, the Media Formats used in case 7, Blinkenlights, are Text, Images, and Video, as well as Abstract Graphics. At one extreme, four cases (7 Blinkenlights, 8 Marnix, 49 Archive Dreaming, and 51 Birloki) support interaction with all four kinds of Media Formats, and at the other extreme, we can identify a number of cases that interact with only one Media Format (15 Spine, 27 Sentiment Cocoon, 47 Fluidic, 52 Living Sculpture, and 53 Lotus Dome). Almost all cases of Bodily Interaction occur with Abstract Graphics, and in only one case, 39 Terrell Place, Bodily Interaction occurs with Images and with Video.

Essentially, any combination of two aspects defines a two-dimensional subspace, so, theoretically, the media architecture design space offers 306 subspaces to consider. Above, we explored the subspace defined by the Media Format and User Interaction aspects, and the next step is to consider the User Interaction subspace and Pixel Shape (see Table 9). In the section above, a one-dimensional perspective on Pixel Shape revealed that the unconventional pixel shapes (3D Polygonal, 3D Spherical, and Irregular) occur in 15 cases; Table 9 reveals that only three of them are Interactive, and that the kind of interaction is Bodily in each case.

	Invisible	Rectangular	Round	Oblong Segment	3D Polygonal	3D Spherical	Irregular
User Application	49	52, 26, 7, 8, 48		28			
Website		26, 8					
Mobile Phone	51			28, 18			
Tangible	33, 49			27, 10			
Bodily	39			28	15	47	53

Table 9. User Interaction (rows) and The Pixel Shape (columns) subspace.

The sub-design space representations such as the ones in Table 8, Table 9, and Table 10 and make densely populated areas of the design space visible at a glance. We find no cases in the area defined by combinations of 3D Polygonal, 3D Spherical, and Irregular Pixel Shapes, and the User Interaction options, except those with Bodily interaction (see Table 9).

	Invisible	Rectangular	Round	Oblong Segment	3D Polygonal	3D Spherical	Irregular
Text	24, 25, 51, 33, 49	3, 7, 8, 22, 23	50	18, 21		19	
Images	24, 25, 51, 32, 39, 42, 49	50, 46	1, 18, 21				
	3, 7, 8, 23						
Video	24, 25, 51, 32, 39, 42, 49, 43, 1	3, 7, 8, 48, 23	50, 14, 2, 5	1, 20, 21	13	19	
Abstract G.	24, 25, 51, 32, 33, 38, 39, 42, 49	52, 26, 3, 4, 37, 7, 8, 9, 48, 44, 23	50, 11, 14, 2, 5	27, 28, 54, 29, 31, 1, 10, 18, 20, 21	12, 13, 15, 6	47, 31, 19, 45	53, 30, 16, 4, 36

Table 10. The Media Format (rows) and The Pixel Shape (columns) subspace.

Similarly, in the subspace defined by combinations of 3D Polygonal, 3D Spherical, and Irregular Pixel Shapes, and the Text, Images, and Video Media Formats, we find only two cases: 13 (C4 Media Façade) and 19 (Hanjie Wanda Square), see Table 10.

As observed in the one-dimensional analysis, the most common Media Format is Abstract Graphics, and Table 8, and Table 10 show that cases that use Abstract Graphics are rather evenly distributed among the five kinds of User Interaction and the seven kinds of Pixel Shape.

	Invisible	Rectangular	Round	Oblong Segment	3D Polygonal	3D Spherical	Irregular
Inseparable	38	3	14, 2, 5, 46	54, 1, 20, 21	12, 13, 6	19	
Integrated	24, 25, 32, 39, 42, 43	26, 7, 8, 48, 44, 22, 23	50, 40, 11	28, 29, 18			
Projection	33, 17					47	30, 16, 36
Installation	51, 49	52, 4, 37, 9		27, 31, 10	15	47, 31, 45	53, 30, 16, 4, 36

Table 11. The Physical Relationship (rows) and The Pixel Shape (columns) subspace.

As a final example of two-dimensional subspaces, we consider the Physical Relationship and Pixel Shape subspace (Table 11), and note that the cases where media architecture is integrated into an existing building, the pixels are predominantly Invisible or Rectangular, and in no cases are they 3D Polygonal or 3D Spherical.

One may argue that Year of Construction and Geographic Region are not truly design space aspects, but when combined with the other aspects, these two kinds of metadata may shed light on the collection of MAB cases. A timeline that presents Year of Construction (Table 12), shows that Tangible Interaction and Bodily Interaction have become more common in recent years, but apart from that, there are no clear, identifiable developments related to User Interaction.

	2012	2014	2016	2018
User Application	52, 7, 8		26, 28	48, 49
Website	8		26	
Mobile Phone		51, 18	28	34
Tangible	10		27	33, 34, 49
Bodily	53	15	28, 47	39, 41

Table 12. Kinds of User Interaction 2012–2018.

	Africa	Asia	Europe	North America	South America	Oceania
Interactive		51, 53, 54, 10, 48, 20	51, 52, 27, 53, 33, 36, 37, 41, 7, 8, 47, 11, 49, 15, 18, 22, 46	25, 51, 26, 28, 34, 39		
Not Interactive	44	29, 1, 3, 5, 6, 38, 43, 16, 19	30, 35, 40, 2, 4, 45, 9, 12, 13, 14, 17, 21, 23	24, 50, 42	32	31

Table 13. Interactivity across Geographic Regions.

Regarding the question of whether there are any differences in Interactivity among Geographic Regions, Table 13 provides part of the answer. The most striking difference is that only 23% of the cases in Asia are Interactive, whereas in Europe and North America they represent 57% and 67% of the instances, respectively.

7 THE DESIGN SPACE AS A GENERATIVE TOOL

In section 4 and 5, The Design Space and Reflections on the Construction of the Design Space, we presented the knowledge generated through the process of decomposing the collection of MAB 2012–2018 instances and the construction of the design space they inhabit, followed by section 6, which provided further knowledge about the collection through an analysis of the design space. For the concluding part of the paper, we propose a way the design space and the knowledge generated thought analysis may be of value in future design projects. More specifically we investigate how the design space may act as generative resource when we design media architecture. The term "generative metaphor" was originally coined by D. Schön to capture how a metaphor may "... generate[d] new perceptions, explanations, and inventions" [29] p 259, [8]. More specifically, we focus on three basic generative creativity mechanisms: use of inspiration, combination, and use of constraints.

Sources of inspiration are commonly sought by designers to spark innovation [9]. For instance, Petre, Sharp, and Johnson have investigated how textile designers find inspiration in existing designs objects, works of arts, and natural phenomena [26], an observation further supported by Mougenot, Bouchard, and Aoussat [25], who have established that car designers find inspiration in three types of sources: intra-domain (car and transportation design) close inter-domain (product design and architecture) and far inter-domain (fashion and lifestyle).

The media architecture collection examined in this paper may serve as a source of inspiration for researchers and practitioners in the field, and may also be valuable to other fields. Identifying sources of inspiration is a common element of card-based design methods [22], for instance, the Inspiration Card method, and as a guideline, it is recommended that both intra-domain and inter-domain sources of inspiration be selected [15, 17]. Our own research laboratory is currently (2021) using the MAB design space as an inter-domain resource in an ongoing project that aims to design interactive solutions for communicating cultural heritage in three historical buildings.

The design space schema that is organized around aspects and their associated options provides an overview of, and the opportunity for open-ended browsing of the design space, which a media architecture designer may use when identifying sources of inspiration relevant to the design task at hand. By filtering the design space with respect to Dynamic Pixel Pattern, it is possible to identify six media architecture cases with such a unique pixel pattern, which may serve as inspiration for new and innovative media architecture. One of the cases is Spine, and another is Megafaces Pavillion, a three-dimensional pixel display used to show images of people captured with a special 3D photo both. The unique, three-dimensional pixel display, consisting of 11,000 RGB-LED pixels controlled by actuators, may serve as

inspiration for other kinds of User Interaction, for instance, Bodily. An even more innovative idea, inspired by Dynamic Pixel Configuration, would be media architecture with Dynamic Pixel Shape, an option not available in the current collection of media cases. Finally, freely browsing the design space may stimulate creativity and lead to innovative design solutions.

The combination creativity mechanism may offer possibilities for developing innovative media architecture solutions. In creativity research, "combination" is defined as bringing together two or more concepts to form a new concept [6, 23, 33]. A well-known example is the integration of an intravenous solution bag into the sole of a shoe, as in the Reebok Pump shoe. An example from the Media Architecture collection is Light Barrier, a light installation based on combining millions of calibrated light beams and a cloud of steam. Another example of combinational creativity is Where do we go from here?, which is based on a combination of industrial robots and light spots in an urban media architecture installation.

The design space schema organized around aspects and their associated options offers an almost inexhaustible resource for innovative ways of combining a design option of one aspect with an option associated with another aspect. One way to identify new opportunities is to pinpoint sparsely populated areas of the design space by selecting a single option (using the + sign) and using the data to spot options that are relevant to only one instance, or no instances at all. For instance, selecting Video as the Media Format reveals that Video is shown only on displays with a 3D Pixel Pattern in one case, and in no cases on a display with a Dynamic Pixel Pattern. A similar observation may be made by selecting Text as the Media Format, revealing that text is shown only on displays with one of the matrix-based Pixel Patterns. Both examples illustrate the possibility of designing innovative media architecture by combing a Media Format option with one of the less populated areas defined by the Pixel Pattern aspect.

The third creative mechanism, use of constraints, is commonly considered productive in design ideation, and works by ignoring aspects of the design situation, for instance, resources, [19]. Notably, constraints may not only constrain, but also enable or advance a creative process [24]. A design space approach to understanding a design situation may provide a platform for managing constraints as part of the creative design process. Deciding to not display Abstract Graphics on media architecture with a 3D Polygonal Pixel Shape is an example of a self-imposed constraint on creativity; another example would be to show Video on media architecture, using a Dynamic Pixel configuration. Both examples are about the designers' choice of selecting an option related to one aspect, and investigating how the design choice first narrows the design space with respect to another aspect, and eventually establishes a hitherto unexplored aspect of the design space.

8 CONCLUSION

Collections of media architecture cases are commonly compiled and organized into main categories, and it is generally acknowledged that previous design cases are important resources for designers. In this paper we applied a systematic approach, supported by a digital tool, to deconstruct a collection of design cases—the MAB 2014–2018 award winners—and to construct the design space populated by these media architecture design cases. The 18 aspects of design and their associated options, organized as a conceptual design space and represented by the design-space schema, offers a comprehensive overview of the design space. The aspect-option sets of the design space schema represent key knowledge about the collection of media architecture cases and the application design space tool have further enabled knowledge generation about the collection by supporting a basic quantitative analysis and an exploration of two-dimensional subspaces providing further insight into the collection of media architecture cases. Finally, we touched briefly on the generative power of the design space approach. The scope of this paper has been to extract and

represent knowledge about a collection of designs, which may be applies in future design projects, similar to volume 2 of Alexander's trilogy presenting the architectural patterns, whereas the knowledge from volume 2 is applied and tested in the subsequent volume 3 (The Oregon Experiment).

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REFERENCES

[1] ag4 mediatecture company. 2006. *Ag4 Media Facades.* Daab Pub, Cologne. 175 pages.
[2] Christopher Alexander, Sara Ishikawa, and Murray Silverstein. 1977. *A Pattern Language.* Oxford University Press, Oxford. 1171 pages.
[3] Michel Beaudouin-Lafon. 2000. Instrumental interaction: an interaction model for designing post-WIMP user interfaces. In *Proceeding of CHI 2000.* ACM, New York, 446–453.
[4] Michael Mose Biskjaer, Peter Dalsgaard, and Kim Halskov. 2014. A constraint-based understanding of design spaces. In *Proceedings of Designing Interactive Systems 2014.* ACM Press, New York, 453–462.
[5] Stuart Card, Jock Mackinlay, and George Robertson. 1990. The design space of input devices. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 1990.* ACM, New York, 117–124.
[6] Fintan J. Costello and Mark T. Keane. 2000. Efficient creativity: Constraint-guided conceptual combination. *Cognitive Science* 24, 2 (2000), 299–349.
[7] Graham Dove, Nicolai Brodersen Hansen, and Kim Halskov. 2016. An Argument for Design Space Reflection. In *Proceeding of NordiCHI 2016.* ACM, New York, 17:1–17:10.
[8] Graham Dove, Caroline Emilie Lundqvist, and Kim Halskov. 2018. The life cycle of a generative design metaphor. In *Proceedings of the 10th Nordic Conference on Human-Computer Interaction - NordiCHI '18.* ACM Press, New York.
[9] Claudia Eckert and Martin Stacey. 2000. Sources of inspiration: a language of design. *Design Studies* 21, 5 (2000), 523–538.
[10] Aron D Fischel and Kim Halskov. 2018. A Survey of the Usage of Sticky Notes. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems.* ACM, LBW080.
[11] George Fitzmaurice, Hiroshi Ishii, and William Buxton. 1995. Bricks: laying the foundations for graspable user interfaces. In *Proceeding of CHI 1995.* ACM Press, New York, 442–449.
[12] William Gaver. 2011. Making spaces: how design workbooks work. In *Proceeding of CHI 2011.* ACM, New York, 1551–1560.
[13] Hank Haeusler. 2009. *Media Facades: History, Technology, Content.* Avedition, Stuttgart. 248 pages.
[14] Hank Haeusler, Martin Tomitsch, and Gernot Tscherteu. 2012. *New Media Facades: A Global Survey.* Avedition, Ludwigsburg. 248 pages.
[15] Kim Halskov. 2010. Kinds of inspiration in interaction design. *Digital Creativity* 21, 3 (2010), 186–196.
[16] Kim Halskov. 2011. CAVI: An interaction design research lab. *interactions* 18, 4 (2011), 92–95.
[17] Kim Halskov and Peter Dalsgaard. 2006. Inspiration card workshops. In *Proceedings of Designing Interactive Systems 2006.* ACM, New York, 2–11.
[18] Christopher Robert Ashton Heape. 2007. *The Design Space: the design process as the construction, exploration and expansion of a conceptual space.* Ph.D. Dissertation. University of Southern Denmark, Faculty of Engineering, The Mads Clausen Institute, Søderborg, Denmark.
[19] Finn Kensing and Kim Halskov Madsen. 1992. Generating visions: future workshops and metaphorical design. In *Design at work: cooperative design of computer systems*, J. Greenbaum and Morten Kyng (Eds.). Lawrence Erlbaum Associates, Hillsdale, NJ.
[20] George Lakoff and Mark Johnson. 2008. *Metaphors We Live By.* University of Chicago Press, Chicago. 256 pages.
[21] Youn-Kyung Lim, Erik Stolterman, and Josh Tenenberg. 2008. The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. *ACM Transactions on Computer-Human Interaction (TOCHI)* 15, 2 (2008), 1–27.
[22] Andrés Lucero, Peter Dalsgaard, Kim Halskov, and Jacob Buur. 2016. Designing with Cards. In *Collaboration in Creative Design*, Panos Markopoulos, Jean-Bernard Martens, Julian Malins, Karin Coninx, and Aggelos Liapis (Eds.). Springer International Publishing, Heidelberg, 75–95.
[23] Michael Mose Biskjaer, Peter Dalsgaard, and Kim Halskov. 2017. Understanding Creativity Methods in Design. In *Proceedings of the 2017 Conference on Designing Interactive Systems - DIS '17.* ACM Press, New York, New York, USA.
[24] Michael Mose Biskjaer and Kim Halskov. 2014. Decisive constraints as a creative resource in interaction design. *Digital Creativity* 25, 1 (2014), 27–61.
[25] Céline Mougenot, Carole Bouchard, Ameziane Aoussat, and Steve Westerman. 2008. Inspiration, images and design: an investigation of designers' information gathering strategies. *Journal of Design Research* 7, 4 (2008), 331–351.
[26] Marian Petre, Helen Sharp, and Jeffrey Johnson. 2006. Complexity through combination: an account of knitwear design. *Design Studies* 27, 2 (2006), 183–222.
[27] Majken K Rasmussen, Esben W Pedersen, Marianne G Petersen, and Kasper Hornbæk. 2012. Shape-changing interfaces: a review of the design space and open research questions. In *Proceeding of CHI 2012.* ACM, New York, 735–744.

[28] Elizabeth B-N. Sanders and Bo Westerlund. 2011. Experiencing, exploring and experimenting in and with co-design spaces. In *Nordic Design Research Conference*. Nordes, Helsinki.

[29] Donald A. Schön. 1995. Generative metaphor: A Perspective on Problem-Setting in Social Policy. In *Metaphor and Thought*, Andrew Ortony (Ed.). Cambridge University Press, Cambridge, 254–283.

[30] Donald A. Schön. 1995. *The Reflective Practitioner: How Professionals Think in Action.* Routledge, Oxfordshire. 384 pages.

[31] Mary Shaw. 2012. The Role of Design Spaces. *IEEE Software* 29, 1 (2012), 46–50.

[32] Robert F. Woodbury and Andrew L. Burrow. 2006. Whither design space. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* 20, 2 (2006), 63–82.

[33] Fritz Zwicky. 1969. *Discovery, Invention, Research through the morphological approach.* Macmillan, Toronto.