Exploratory making: Shape, structure and motion

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Exploratory making activities can support the reasoning processes through which new designs are developed. With a focus on physical model-making of kinematic designs, this paper considers how these activities and processes can be articulated using formal generative rules. For kinematic designs where connections between parts afford relative motions, rule-based descriptions defining variable spatial relationships can both construct and transform models. Through modifying both shape and structure, spatial relations essential for achieving the motion characteristics of a kinematic design are identified. Unsuccessful modifications support discovery of limits to design changes, illuminate how designs work, and inform the generation of new design variations. The need for active manipulation of physical models, both to examine motions and to implement design changes, is highlighted.

Keywords: kinematic designs, design method, creative design, reasoning, reflective practice

In design, making appears to support the generation of new knowledge about both the use of tools and materials, and designs themselves (Ingold, 2009, 2013). Exploratory making can play a role in both analysis and synthesis, supporting the process of generating new designs, whilst also affording reflection and reasoning about their properties.

In kinematic design, physical models can support a direct appreciation of motions. In design development, modifications can be made directly to both the shape (of parts), and the structure (of connections between parts). Motion, as the primary property of interest, is a function of relationships between the shapes of parts and their connections in a design. These relationships can be complex, and visual examination of static descriptions, or even graphical simulations, may not adequately support a designer in understanding how parts move. For particular classes of kinematic designs, mathematical techniques can be used to predict motions (Hunt, 1978; O'Rourke, 2011; Phillips, 2007). For complex designs with many parts, these techniques may not reveal easily the effects of changes to shape and structure, and therefore it can be difficult to anticipate how design modifications may affect motions. Physical

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model-making supports direct experience of motions through active manipulation of the model. For instance, Harrison, Earl, and Eckert (2011) describes how 3D printed physical models can afford an appreciation of the motions of a class of mechanisms (Figure 1). Exploratory making can also permit design modifications to be directly applied and tested.

This paper examines exploratory making through the lens of creative computational search. Computational exploration can make it feasible to systematically consider possible design variations, and can provide insights into relationships between design properties. For designs with moving parts, those relationships of interest are between properties of shape, structure and motion. For example, the 'twisted' shapes of the connected elements of the kinematic designs in Figure 1 avoid collisions between the elements and afford continuous full-cycle motion.

Creative exploration has been likened to a process of searching within an abstract space of possibilities. This analogy is attractive as it lends itself to the use of computation (Boden, 2004; Wiggins, 2001). In this view of creative discovery, theoretical spaces, containing both complete and partial solutions, can be explored to find new design possibilities. Boden suggests that individual creative processes enable the navigation of these spaces in distinct ways, with one method able to reach a solution that is inaccessible to another. Wiggins has further formalised this perspective, suggesting that these processes might be described using sets of rules. Yet how these theoretical exploration rules, and the abstract spaces they traverse, might meaningfully relate to the tangible world in which practical design exploration activities take place is unclear. Here we examine how a rule-based approach to creative search can support a more systematic approach to practical design exploration, and consider how the actions and reflections that support design reasoning through exploratory making might be described in broadly computational terms.

In complex, situated practices, several types of activity may occur simultaneously. Schön (1992) describes design as a process of action and reflection, which responds to the materials of the design situation. The nature of situated practices in other fields is also discussed by Suchman (1987) and de Certeau (1988). Their concepts of situated actions, and tactics, respectively, may be applicable when studying design exploration activities.

As the processes that constitute making are inherently generative, we discuss how the activities and steps within an exploratory making process for designs with moving parts can be described using generative rules. We examine how these 'making rules' can help to articulate design reasoning processes, and support a more systematic exploration of a given design space, revealing underlying relationships between shape, structure and motion for a particular set of designs. Our method uses the design of a single existing object as a starting