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Affordances of agricultural systems analysis tools: A review and framework to enhance tool design and implementation

Lenora Ditzler[a,*], Laurens Klerkx[b], Jacqueline Chan-Dentoni[a,b,c], Helena Posthumus[c], Timothy J. Krupnik[d], Santiago López Ridaura[e], Jens A. Andersson[b,e], Frédéric Baudron[f], Jeroen C.J. Groot[a]

[a] Wageningen University & Research, Farming Systems Ecology Group, P.O. Box 430, Wageningen 6700 AK, The Netherlands
[b] Wageningen University, Knowledge, Technology and Innovation Group, Hollandseweg 1, Wageningen 6706 KN, The Netherlands
[c] Royal Tropical Institute (KIT), Mauritskade 64, Amsterdam 1092 AD, The Netherlands
[d] International Maize & Wheat Improvement Center (CIMMYT), Sustainable Intensification Program and CGIAR Research Program MAIZE, House 10/B, Road 53, Gulshan-2, Dhaka 1213, Bangladesh
[e] International Maize & Wheat Improvement Center (CIMMYT), Sustainable Intensification Program, Apdo. Postal 6-641, Mexico City, DF 06600, Mexico
[f] International Maize and Wheat Improvement Center (CIMMYT), 12.5 km Peg Mazowe Road, Harare, Zimbabwe

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ABSTRACT

The increasingly complex challenges facing agricultural systems require problem-solving processes and systems analysis (SA) tools that engage multiple actors across disciplines. In this article, we employ the theory of affordances to unravel what tools may furnish users, and how those affordances contribute to a tool's usefulness in co-design and co-innovation processes. *Affordance* is defined as a function provided by an object through an interaction with a user. We first present a conceptual framework to assess the affordances of SA tools. This framework is then applied in a literature review of three SA tools used in agricultural systems research (fuzzy cognitive mapping, bio-economic whole-farm models, and role play and serious games). Through this exercise, we extend the SA tool design and implementation dialogue by illuminating (i) links between lower-level affordances, tool design, and heuristic functioning, and (ii) the central role of use setting and facilitation in mobilizing higher-level, productive affordances. Based on our findings, we make five propositions for how SA tool design and implementation in participatory problem-solving settings can be improved.

1. Introduction

The challenge of reconciling food security and agricultural production issues within changing ecological conditions, political climates, market structures, and development goals (Foley et al., 2011; Godfray et al., 2010) requires problem-solving approaches suited for handling dynamic and entangled system variables and drivers. Incorporation of the divergent viewpoints of multiple stakeholders is equally crucial (Le Gal et al., 2011; Meynard et al., 2017; Schut et al., 2015). To identify practical solutions that are credible, salient, actionable, and legitimate, direct involvement of stakeholders in research on social–ecological systems (including agriculture) has been widely advocated (e.g. Cvitanovic et al., 2016; Fazey et al., 2014; Raymond et al., 2010; Reed et al., 2013). Stakeholder involvement is also part of current approaches that strive for what have been called co-design and co-innovation processes in agricultural systems (Botha et al., 2017; Dogliotti et al., 2014; Meynard et al., 2017). Assembling stakeholders, however, is often not enough to move agriculture towards sustainable redesign (Berthet et al., 2016). Effective multi-stakeholder involvement in collaborative processes requires “mechanisms that promote change in understanding of the individuals involved and the cogeneration of new knowledge” (Reed et al., 2013, p. 318). Such mechanisms should facilitate knowledge exchange, co-learning, reframing of problems and solutions, and co-innovation (Hermans et al., 2017; Jones et al., 2017; Schindler et al., 2015; Voinov and Bousquet, 2010). This has implications for how scientists support stakeholder involvement: if scientific knowledge is to be “put to use” in the real world, participatory approaches must be aimed at catalyzing action (Geertsema et al., 2016; Schut et al., 2014).

In the agricultural sciences, a range of systems analysis (SA) tools have been applied to support problem solving in the context of co-design and co-innovation processes. These include, but are not limited to, computer-based models (e.g. Le Gal et al., 2011), cognitive mapping (e.g. Christen et al., 2015), serious gaming (e.g. Speelman et al., 2014),

* Corresponding author.
E-mail address: lenora1.ditzler@wur.nl (L. Ditzler).

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innovation dynamics diagnostics (e.g. Schut et al., 2015), and decision support systems (e.g. Rose et al., 2016). SA tools facilitate integrated analyses of agricultural systems by incorporating environmental, economic, social, and political perspectives (van Ittersum et al., 2008). This enables assessment of the behavior and processes of interacting entities within a system (e.g. biophysical components, stakeholder concerns, market dynamics, policies, etc.). SA tools may also provide artifacts, visualizations, or discourses through which different actors can navigate both congruence and disagreement around key issues and decision making (Jakku and Thorburn, 2010; Klerkx et al., 2012a). While SA tools have the capacity to act in such a manner, an enduring challenge is to understand to what extent SA tools can be designed to function in this way.

Both long-standing (e.g. McCown, 2001) and more recent (e.g. Cerf et al., 2012; Jakku and Thorburn, 2010; Sterk et al., 2009) critiques citing the limited uptake of agricultural SA tools have called for a rethinking of how to enhance tool appeal and ease of use. Of key interest is the often-missing link between a tool's design and its intended use setting or target audience (Cerf et al., 2012; Prost et al., 2012; Ravier et al., 2016; Sterk et al., 2011), which may leave research results unused by stakeholders due to a tool's complexity and/or institutional, cultural, and language barriers (Cvitanovic et al., 2016). To this end, the participatory design and implementation of SA tools in agricultural systems settings has been widely advocated (e.g. Cerf et al., 2012; Delmotte et al., 2017; Jakku and Thorburn, 2010; Prost et al., 2012; Voinov and Bousquet, 2010). Why a participatory approach is needed has been well elaborated; however, *how* the design of SA tools contributes to their usefulness in collaborative problem-solving processes remains largely unexplored (Matthews et al., 2011).

We address this gap in light of current debates on next-generation SA tools in agriculture, which draw attention to the need for more collaborative, flexible, accessible, transparent, and interdisciplinary approaches to solving complex system problems (Duru et al., 2015; Janssen et al., 2017; Jones et al., 2017; Kragt et al., 2016; Martin, 2015). We consequently employ the concept of affordances, defined broadly as what an object provides in an interaction with a user (Gibson, 1979). Affordance theory has been applied in science and technology, education, and design studies. To our knowledge, however, it is unused in agricultural systems sciences. We hypothesize that affordance theory can help unravel links between *what* a tool furnishes users and *how* those affordances contribute to a tool's usefulness in participatory agricultural problem-solving processes. We posit that a better understanding of the affordances of SA tools, and therefore their potential and limitations, can inform how SA tools may be designed for improved affordance. Affordance analysis can also help identify how SA tools may need to be adapted or used complementarily in portfolios to meet the objectives of diverse users.

In this article, we present a conceptual framework for identifying and classifying the affordances furnished by SA tools in participatory problem-solving settings. Based on literature review, we demonstrate how this framework can be employed to assess three SA tools widely applied in agricultural systems: fuzzy cognitive mapping (FCM), bioeconomic whole-farm models (BEFM), and role play and serious games (RPSG). Next, we discuss key contributions and limitations of the affordance framework to facilitating a better understanding of what SA tools provide in collaborative design and innovation processes, thereby exploring how they may enhance such processes. We conclude with five propositions for how SA tool design and implementation can be improved, with an emphasis on the role of affordances in participatory use settings.

2. Conceptual framework for affordance analysis of SA tools

2.1. Affordance theory

Gibson (1979) first defined affordances in the context of ecological psychology: “The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill” (p. 127, italics original). Since Gibson's introduction, the concept has been adopted in other disciplines, notably in product design, science and technology studies, and educational studies, where it has been used primarily to understand what objects and technologies afford users and therefore to drive their design towards more intuitive and effective operation (Antonenko et al., 2017; Bower and Sturman, 2015; Srivastava and Shu, 2013). As our focus is on SA tool design and implementation, we draw most from the affordance literature in the design field to build our conceptual framework.

Central in the literature is the notion that affordances emerge from an “entangled relationship” (Maier and Fadel, 2009), that is, the interaction between designers, artifacts,[1] and users (Bernhard et al., 2013; Norman, 2013). While a designer can to some extent direct the way an artifact is used by designing it with specific affordances in mind (Maier and Fadel, 2009), a user may not necessarily be interested in, aware of, or able to actualize those affordances (Norman, 2013). As a relational concept (Gibson, 1979), an affordance must be measured relative to a user's abilities and needs: particular users have particular goals and expertise which drive their interaction with the artifact. This may lead different users to derive different affordances from the same artifact (Bernhard et al., 2013). A simple example is a chair. For an adult of a certain height and weight, a chair affords sitting. For a crawling baby, a chair does not afford sitting, but might afford grasping or support while attempting to stand. In our analysis of SA tool affordances, we adopt the relational design approach, and consider the tool designer in addition to the tool and the tool user (Hartson, 2003; Maier and Fadel, 2009; Norman, 2013).

We conceptualize affordance emergence from SA tools as the result of interactions between a tool, its designer, the tool use setting, and the studied system (Fig. 1). We build on the framework for affordance-based design described by Maier and Fadel (2009). In our conceptualization, the tool designer is directed by information about the system's characteristics and the user's objective(s). The designed tool is then equipped with potential affordances which may emerge through interaction with users, who are driven by their unique abilities and needs and operate within a unique setting. These affordances may in turn be activated within the system.

2.2. A layered model of affordance emergence

Unpacking the interaction between tool and user is required to understand affordance emergence and activation. To untangle this dynamic, several authors have proposed methods to classify affordance perception and actualization as discrete concepts. Drawing from four theoretical threads in the affordance literature (Bernhard et al., 2013; Bower, 2008; Burton-Jones and Grange, 2013; Markus and Silver, 2008), we conceptualize affordance emergence as a layered model in which *structural* and *functional* affordances are distinguished.

We define *structural* affordances as the objective material features, properties, or capabilities of a tool. These dictate what the tool itself does (e.g. collate data or produce a system map). Structural affordances are determined by the tool designer, who delineates tool boundaries in the development process. Complementarily, we define *functional* affordances as what the tool enables when a user interacts with structural affordances, for example an overview of the current system state.

To further untangle the emergence of functional affordances, we combine Bower's (2008) classification of functional affordance types with Burton-Jones and Grange's (2013) first- and second-order affordances, distinguishing first-order *instructive* (clarifying or deepening system

[1] In the affordance design literature, the objects of study are usually tangible (e.g. door handle, wine bottle opener, light switch), and are often referred to as artifacts to denote human fabrication.