Supplementary Material 1

Table S1. List of the selected papers with some of the key elements

Author	Year	Geographical Location of Studies	Citation Count	Research Themes	Keywords	Definition
Ervin	2016	United States	2	integrated technology	interdisciplinary; public participation; techniques; design process	"systems-oriented-planning-and-design-for-large-complex-projects-by-interdisciplinary-teams-and-public-participation-using-computers-and-other-digital-devices-and-representations-together-with-GeographicInformation Systems (GIS)- Computer Aided Design(CAD)-BuildingInformation Models (BIM)-and-other-algorithmic-techniques including-timely-simulation-and-impact-assessments"
Steinitz	2012	United States	329	People of the place, geographic sciences, deign professions, information technology	People, science, design, technology	"geodesign is systems thinking … geodesign is serious … geodesign is complex: there are uncertainties … geodesign support must be flexible, iterative, transparent and rapid … geodesign is dynamic … geodesign is communication … geodesign is a collaborative social-political process of design."
Wilson	2015	United States	26	GIS and technology	critical GIS;design; science; geography; technology	"the academic disciplines of design, planning, and geography that are also being reconfigured as technoscience, as geospatial infrastructure and tools change alongside the necessary curricula to train new workforces thereby enabling a fusing of technology and science"
Fisher	2016	United States	1	geodesign education	design for future; community engagement	"… the visualization and assessment of alternatives futures using design thinking … and a method of engaging people - customers, community members, suppliers, and stakeholders - in the co-creation of new products and services, policies and procedures"
Campagna	2016	Italy	3	design process	design process; multidisciplinarity; community engagement; decision making	"Geodesign entails complex processes involving multidisciplinary teams of stakeholders and communities in devising and choosing sustainable future development scenarios for professionals supporting their territories ... is characterised by the integrated usage of Geographic Information Science methods and tools to transform spatial data into relevant knowledge for informed design and decision-making"
Campagna	2014	Italy	20	community engagement and social technology	design process; geographic science; community engagement	"… an approach to planning and design as an integrated process which includes project conceptualizations, knowledge building, design of alternative scenarios, evaluation of impacts, decision-making, collaboration and participation, wherein all activities are grounded on robust scientific geographic knowledge support"

Hayek et al.	2016	Switzerland	3	procedural design approach	systems thinking; collaborative design process; geographic context	"… introduce the required information into the design process … Geodesign seeks to implement (digital) tools and approaches, using geographic knowledge in order to collaboratively design and improve future environments informed by systems thinking … the larger geographic context is considered, focusing on the interconnected dynamics of the landscape systems"
Cerreta et al.	2016	Italy	4	iterative geodesign process	iterative design process; multiple scales and disciplines; modeling and simulation	"Geo-Design incorporates elements of sketching and design, but also elements of modelling and analysis ... to facilitate life in geographic space, enhancing collaboration, scenario generation, monitoring of implications, ongoing feedback, and evaluation and selection of optimal designs that reflect a community's needs and visions for the future ...covers a variety of scales, bridging the gap between regional and local contexts ... an iterative design method that uses stakeholders' input, geospatial modelling, impacts simulations, and real-time feedback, to facilitate holistic designs and smart decisions"
Li & Milburn	2016	United States	2	geodesign history, theories, methods and practical tools	collaborative design process; systems thinking toward complexity and dynamics; technology for public engagement	"geodesign as providing following tools fordesigners: (1) science-based design; (2) value-based design; (3)interdisciplinary collaboration; (4) system design to man-age complexity; (5)improving the quality and efficiency of design; (6) maximizingsocial benefits while minimizing social costs; (7) addressing issues over both space and time; (8) advanced tools including online interfaces, handheld GIS tools and idea-driven graphic technologies"
Moura	2015	Brazil	10	geodesign framework and parametric modeling	framework; modeling and simulation; design process; interaction	"… a six-step framework that can be viewed as models of characterization, analysis, landscape simulation and evaluation. It supports decision interactions that allow different actors to understand and participate in the urban question"
Muller & Flohr	2016	United States	1	geodesign education	technology; multidisciplinarity; modeling and simulation	"Geodesign is rooted in use of digital technologies that integrate information about social and natural systems as a basis for modeling, analysis and communication of design and plan effects. Finally Geodesign training tends to cross disciplinary boundaries and thus is distinguished from traditional design education focusing on single career paths"
Aina	2013	Saudi Arabia	3	geodesign and sustainable urban design	synergy; sketching; modeling and simulation; iterative design process; systems thinking with feedback consideration	"… the adaptation of geography, geographic information system and other information systems in a synergetic way to support urban design … including the following essential elements: 1) Sketching – drawing proposed designs or plans; 2) Spatially aware simulations – modelling different systems (environmental, economic and so on) and how they will respond to proposed design in terms of impacts and change (with geographic reference); 3) Fast feedback – supporting

						collaboration; 4) Iteration – trying and visualizing different alternatives; 5) 3D visualization – presenting design alternatives and impacts in three dimension"
Flaxman	2009	United States	60	geodesign fundamentals	modeling and simulation; geographic science; design process	"Geodesign is a design and planning method which tightly couples the creation of a design proposal with impact simulations informed by geographic context"
Slotterback	2016	United States	7	geodesign and practical case study on multifunctional landscape	geographic science; design process; social engagement	"geodesign can be characterized by three facets … 1) geography by design; ... 2) sketch and simulation accomplished through the technology of design; … 3) incorporates scientific knowledge, integrates with human decision-making, and allows decision makers to enact the pattern-process-design relationship"
Trubka	2016	Astralia	14	technical development and pratical case study	geographic science;design process; PSS	"embraces the intersection of geography and design … the development of a new suite of planning support tools to aid the design and planning of cities, particularly at the scale of precincts"
Miller	2013	United States & Belgium	37	geodesign and a measurement framework for transportation planning	framework; integration of methods and technologies; design process	"… geodesign provides a framework for organizing methods and technologies for constructing livability indicators, as well as integrating livability measurement into the transportation planning process"
Campagna	2016	Italy	2	geodesign and regulations	integration of methods and technologies; design process; collaboration; community participation	"Geodesign entails the application of methods and techniques for planning sustainable development in an integrated process, from project conceptualization to analysis, simulation and evaluation, from scenario design to impact assessment, in a process including stakeholder participation and collaboration in decision-making strongly relying on the use of digital information technologies"
Ervin	2011	United States	43	system for technological development	technology; multidisciplinarity; modeling and simulation; systems thinking	"… usually multidisciplinary, across a range of domain areas, and that they feature a relatively tight coupling between ideation (design) and evaluation or 'generate' and 'test' ... leverage the powers of digital computing and communications technologies to foster information-based design and provide timely feedback about implications of proposed designs, often including impacts and evaluations covering a larger area, greater complexity, or longer time-frame than the immediate design proposal"

Supplementary Material 2

Steinitz's geodesign framework and its corresponding concepts of systems thinking

In table S2, we summarize our geodesign framework by linking with systems-thinking concepts and the Steinitz [10]. The "representation models" are used to identify the significant systems/elements in the studied landscape. It helps identify features and relevant issues. It also helps

define the inherent hierarchies present within the existing landscape that help determine scale and interconnections to frame the contexts. In the "process models", we should understand the dynamic interconnections among the hierarchical levels. Incorporation within the different levels is critical for geodesign teams to digest the complex processes and mechanisms of the important elements involved in the study area. Moreover, leveraging such incorporations in design does not bring local benefits right away; it generates additional services long after the design is completed and extends the services to surrounding areas. The "evaluation models" should identify evaluation measures by considering how to achieve adaptability of the study area and of the people who participate in the geodesign collaboration. "Adaptive capacity" also suggests continual learning over time through systems' changes and experience, which demonstrates the necessity for participants to constantly take the evaluation measures into consideration during all geodesign processes. In the "change models", we should explore possible scenarios by modeling and simulation to evaluate current and future conditions [11]. The classification of scenarios should be defined by the objectives of the project through effective communications of people from different perspectives. The "impact models" investigate the feedback loops underlying the changes from the change models, and respond positively to the feedbacks through appropriate design strategies. When geodesign teams respond positively to the feedback loops through sustainable strategies, the larger landscape system can advance sustainability across multiple scales. When we fail to understand feedback, the landscape system may become vulnerable to disaster [12]. In this model, we should also explore what new structures, patterns and properties of landscape might emerge from the system's self-organization during the changes. The "decision models" aggregate systems thinking concepts and previous models.

Table S2. The geodesign framework [1] and corresponding core concepts of systems thinking.

Models of geodesign framework	Core concepts of systems thinking
Representation models How should the study area be described?	**Hierarchy** What decomposable systems are central to our studied landscape and where are they located in a nest structure?
Process models How does the study area operate?	**Interconnections** How are the central systems interconnected through what direct effects or feedback loops? **Self-organization** What patterns does the existing landscape includes because of self-organization? **Cross-scale dynamics** How to describe the spatial, temporal, quantitative and analytical dimensions of the central systems?
Evaluation models Is the current study area working well?	**Adaptive capability** What measures might be used to evaluate the adaptability of the study area and people?
Change models How might the study area be altered?	**Scenarios and testing models** What possible scenarios might be made by considering the measures created in the evaluation models?
Impact models What differences might the changes cause?	**Feedback loops** What direct effects and feedback loops might the changes cause? **Emergence** What new structures, patterns, and properties of landscape might arise from systems themselves because of the changes?
Decision models How should the study area be changed?	All concepts

Supplementary Material 3

Methodology

To identify existing perspectives, definitions and theories of geodesign, we conducted a thorough review of all found literature related. We used the systematic literature review methodology developed by Tranfield, et al. [13] and Williams, et al. [14] to select articles for review. This methodology resulted in an initial collection of 1,023 articles and a final set of 75 papers. We didn't use the same methodology to search, screen and analyze the articles about ecological systems thinking because of its gigantic amounts. However, it has also been reviewed and served as an

important methodological approach for the whole process. With a diagram (Fig. S3) showing the processes and corresponded results, we explain the method we used to select articles below.

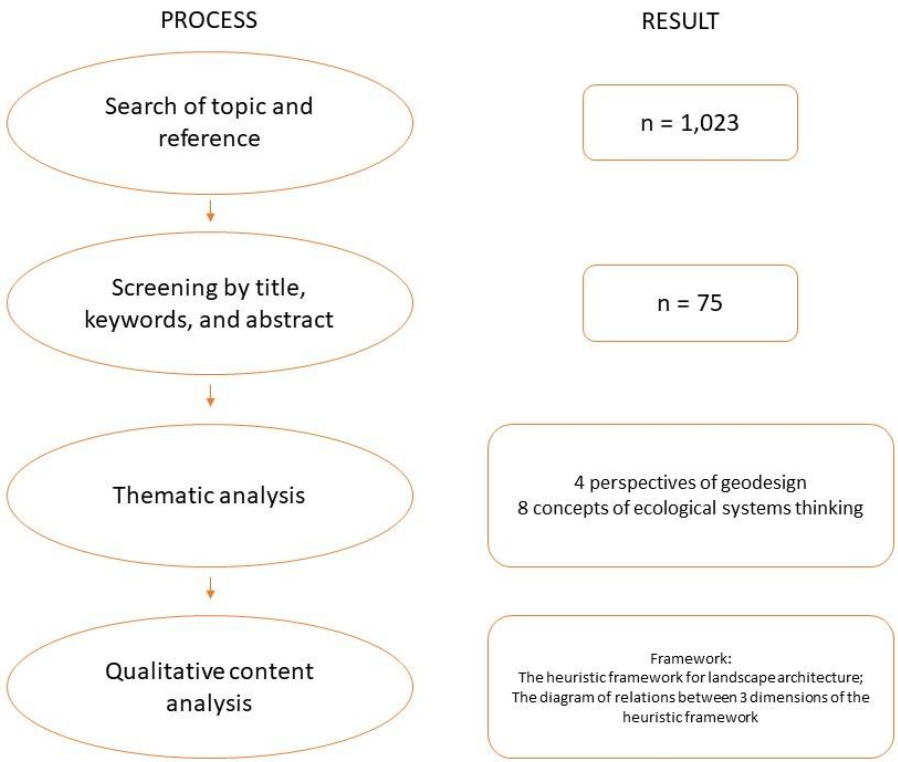

Figure S3. Processes and corresponded results of the research method

2.1. Search

Phase 1: First, we set the major criteria for this review: i) review topic: geodesign, systems thinking; ii) review context: multiple disciplines; iii) dimension of time: published online between 1990 and 2017; iv) dimension of space: all over the world; v) language: English.

Phase 2: Then we conducted an extensive search using multiple databases: Google Scholar, Scopus and the Web of Science. We used two keyword strings to identify related articles. The first keyword string ensured the articles are related to geodesign. The second string was developed to capture articles related to landscape architecture, which was selected in filers. Our database search showed that there were no previous reviews published on systems thinking and geodesign.

Phase 3: Using the same selection criteria in Phase 1, we also conducted a reference list search and cited reference search from the full-text articles found from the databases above. For newly-identified articles, we repeated the reference search until no additional articles were found. This process identified 1,023 potentially relative articles for the review.

2.2. Screening

Phase 4: We began the screening process by reviewing the titles, keywords and abstracts. In this procedure, we coded each article either 'related,' 'unrelated' or 'not-sure.' The 'related' articles were determined to be thematically relevant to my objectives. The 'unrelated' articles were those not applicable to geodesign-related or environmental-related studies. For the 'not-sure' category, we reviewed full articles based on the same screening criteria. This stage reduced the number of papers to be used in the review to 75.

2.3. Thematic analysis

Phase 5: A thematic analysis was conducted using deductive codes including empirical or conceptual, level of analysis, contribution to literature, methods used, etc. [14]. The theoretical deductive codes were acquired from the literature: human-environment systems [15], geographic sciences [10], iterative design process [16], community collaboration [5], and systems-thinking scopes including hierarchical systems, interconnections, functions, feedback loops, delays, dynamics, etc. [17]. The thematic analysis ultimately resulted in 4 theoretical perspectives of geodesign (Fig. 2) and core concepts of ecological systems thinking (section 3.2).

2.4. Qualitative content analysis

Based on the method of qualitative content analysis developed by Luederitz, et al. [18], we explored similarities and differences of the literature to create the conceptual framework. In this phase, we identified the major geodesign concepts used in each article. In the qualitative content analysis, we first paraphrased each concept to extract the core contents into keywords. Second, we integrated these geodesign concepts with ecological systems theory. To do so, we compared their keywords. If similar, they were integrated. If different, they became new complementary concepts. If a geodesign concept corresponded to more than one concept of ecological systems theory, we compartmentalized it. Third, we summarized and categorized the examined concepts into several groups to set up the main structure of the framework (Fig. 4). Fourth, we identify the interrelationships of each group of concepts to accomplish the holistic framework (Fig. 4 & Fig. 5).

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