

# A Framework for Developing Scalable GeoDesign Products

Elizabeth Bastian; Juliana Wilhoit; Matthew Hielt; Noah Garfinkle; George W. Calfas;  
Thomas Foltz; Natalie Myers

US Army Engineer Research and Development Center, Construction Engineering  
Research Laboratory, Champaign, IL

## What is Geodesign?

While geodesign is a relatively recent addition to the geographic information systems (GIS) lexicon, the basic concept has been in existence for decades, if not centuries (Miller 2012). According to Carl Steinitz, author of *A Framework for Geodesign: Changing Geography by Design*, geodesign is not new. Rather, geodesign is a set of concepts and methods derived from both geography and other spatially oriented sciences, as well as from design professions, including architecture, landscape architecture, urban and regional planning, civil engineering, and others (Steinitz 2012).

There is no singular agreed-upon definition of geodesign, though most definitions encapsulate similar ideas and goals of the process. Michael Flaxman, an urban planner, defines geodesign as a "...design and planning method which tightly couples the creation of a design proposal with impact simulations informed by geographic context" (Flaxman 2009). Stephen Ervin, a landscape architect, emphasizes the natural and environmental aspects in his definition while expanding on the modeling capabilities:

*"Geodesign is environmental design usually involving large areas, complex issues, and multi-person teams, that leverages the powers of digital computing, algorithmic processes, and communications technologies to foster collaborative, information-based design projects, and that depends upon timely feedback about impacts and implications of proposed designs, based on dynamic modeling and simulation, and informed by systems thinking" (Ervin 2013).*

Taking both of those definitions into consideration, Tess Canfield and Steinitz refined geodesign as a process which "applies systems thinking to the creation of proposals for change and impact simulations in their geographic contexts, usually supported by digital technology" (Tess Canfield 2014). In sum, geodesign allows for planning and forecasting across scales among professionals with diverse backgrounds using GIS technologies.

Geodesign, by its nature, is a multi-disciplinary decision-driven process that seeks to leverage geoscience and design practices. Geodesign seeks to elaborate on the "science" aspect of geoscience by extending the analytical role of traditional GIS into a solution production area

(Jensen 2011). Through the creation of intuitive and spatially explicit tools and models, geodesign encourages diverse participation in the planning process while lowering the required technical knowledge previously needed to utilize GIS planning tools.

The US Army Engineer Research and Development Center (ERDC) has consistently been at the forefront of creating innovative solutions and technologies used by American fighting force, enabling them to conduct safe and successful operations. The 1980's open-source GIS tool GRASS, developed by the US Army Engineer Research and Development Center, has been identified as a starting point for computer aided suitability and geodesign with its focus on integrating science and geospatial analysis. Goodchild (2010) further identified the framework of funding for GRASS as being a possible way to jumpstart a large-scale geodesign program.

This legacy of geodesign at ERDC, of building decision-driven digital technologies based on a cross-disciplinary approach to GIS and design, is continued today. ENSITE, or Engineer Site Identification for the Tactical Environment, is a multimodal, holistic software product developed for the military for placing combat infrastructure utilizing both commercial off the shelf software such as ArcGIS and ENVI and open-source modeling tools such as R and Python. A diverse project team was readily able to translate scientific and engineering processes into spatially enabled suitability and design tools through a geodesign-based, four-part framework consisting of global data, flexible backend, rapid development, and subject matter expertise.

## **ENSITE: Geodesign for Deployed Force Infrastructure Solutions**

The Engineer Site Identification for the Tactical Environment (ENSITE) is desktop software application for assessing the built, natural, and social characteristics of locations for suitability in siting deployed force infrastructure, a phrase which encompasses bases and accompanying infrastructure constructed to assist troops in theater. ENSITE strives to be the front end and dashboard for connecting survey and geospatial data for engineer site selection and operation. Developed in agile sprints, there are several innovative and geodesign-related elements which enable ENSITE to provide both survey and geospatial services for users with a wide range of GIS knowledge. These include a map-based user interface, support for integration of pre-built geospatial tools and workflows, manipulation of data sources into accessible global coverages, and army-specific data validation and governance processes.

ENSITE is multidisciplinary and holistic in both conception and execution. The program was developed by a research team from ERDC and is sponsored by the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA(ALT)) with a funding timeline of October 2015 to September 2018. In just over a year from the official project start date, ENSITE has already established partnerships and integration processes with several other key operational research projects and programs already in use within the Army. The Virtual Forward Operating Base (VFOB), a computer aided design (CAD) based program for detailed contingency base camp siting with which ENSITE is interoperable, has allowed a full life cycle of design to happen. Another partner program is Instrument Set, Reconnaissance and Surveying (ENFIRE),

a multi-modal site reconnaissance suite. These particular partnerships are instrumental in helping ENSITE implement principles of geodesign in the real world.

## ENSITE's Geodesign Framework



Figure 1 Two screen shots representing the geodesign software, ENSITE. The left demonstrates a the multi-criterion decision analysis run for the area. The right shows a view shed analysis for one base.

In his 2012 book on geodesign, Steinitz puts forth a framework for carrying out geodesign studies, shown in Figure 2 (Steinitz 2012). Utilizing the efforts of both the geodesign team and relevant stakeholder input, the framework involves 3 iterative loops through six key questions: the first to understand the study area (“why”), the second to establish methodology (“how”), and the third to actually conduct the study (“what”, “where”, and “when”). Establishing and following such a framework can foster collaboration among science and design professionals, ensure stakeholder inclusion, and provide a platform on which better informed, decision-driven results are produced.

### The geodesign framework – by Carl Steinitz

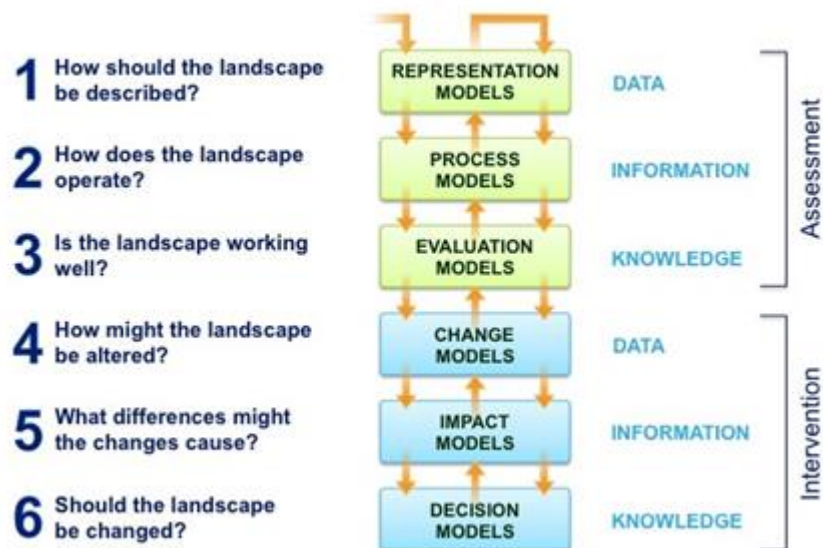


Figure 2 Graphic of iterative design process where questions are asked three times in the creation of a proposal for landscape change. Source:(Steinitz 2012)

Although the Steinitz framework may seem, in his own words, “excessively linear,” he notes that the application is rarely linear in practice (Steinitz 2012). Variations, due to any number of anticipated or unanticipated factors, are to be expected. As ENSITE never intended to be a singular study, either in geographical or temporal terms, the Steinitz framework initially seemed almost irrelevant. However, while the ENSITE team may not have followed this framework in the production of the desktop software application, we desired to provide a program within which users could work through these essential geodesign questions to produce their own suitability and survey studies for specific locations and times. In this way, the ENSITE software is able to walk users through all of Steinitz’s steps.

Steinitz believes (and the authors here agree) that creativity and invention in geodesign are most successful when well prepared for and applied in a clearly organized framework (Steinitz 2012). So while the questions posed and models utilized in the Steinitz framework became more of a way to determine user workflows, the ENSITE team recognized the need to establish a unique framework to guide the project as a whole that still ensured the incorporation of basic geodesign principles. In order to successfully develop and deploy ENSITE products, a four-part geodesign-based framework was utilized to lead the development process. These framework components are: 1) Global Data, 2) Flexible Backend, 3) Rapid Development, and 4) A Diverse Team of Subject Matter Experts.

As a tool that aims to provide survey and geospatial planning support for any possible operating environment, a basis of **global-level data** was absolutely essential. This data can be scaled from the global level to the regional or local level. The acquisition, governance, and processing of this data is handled within ENSITE HUB, which allows users to acquire datasets that will later be used in decision-making software plug-ins. The data gathered by HUB is a portable and consistent file structure which remains consistent for each geographic location.

The **flexible backend** of ENSITE lets developers on the research team code in multiple languages, and lets users add in additional capabilities according to their existing knowledge base. A flexible backend also eases the integration with other Army programs like VFOB and ENFIRE, enables the use of existing proprietary software, open-source software, and APIs.

One of the cornerstones of the ENSITE development process is the adoption of **rapid development**. Rather than spending months or years on a feature before putting it in the hands of future users, we concentrated our efforts on the rapid development of analysis followed by user engagement. Rapid development allowed our team to quickly pivot and change course as needed.

**A team of subject matter experts (SME)**, has been present in both the members of the research team and the efforts to incorporate input from current and former Army service members. The research team comprises over forty researchers with expertise ranging from archeology to coastal management. The team is structured into three loose sub-teams--

programming, data, and application development. Though diverse, these teams foster collaboration between researchers, and have truly propelled the team as a whole to success.

## Methods

Determining suitable locations for deployed forces is a multi-layer decision process to support the mission and commander's intent. Deployed force infrastructure (including base camps) locations and designs are hardly uniform, each with particular needs ranging from proximity to an airfield to distance to water. Much like Steinitz's six framework questions and accompanying models, ENSITE tools access the landscape progressively through a series of analysis. The analysis begins at a regional level, looking broadly at the areas where a user is interested in placing deployed force infrastructure with the goal of developing an initial suitability map. The scale of this analysis could range from a city scale to a nation-state. Users are asked to place weights on a variety of factors, such as cultural sites protected by UN Conventions and slope. Included factors were chosen based on Army doctrine and feedback from users. Using coarse data (approximately 30 meters), an efficient area-specific analysis is easily produced. The result is a stop-light map (red, yellow, green) indicating the suitability for construction based on the weights and factors presented. From these results and localized knowledge, users then are prompted to run an additional series of analyses to gather site specific information. These analyses include soil suitability for construction, flood zones, and viewsheds.

## Global Data

Global data allows ENSITE to be run for any location on the planet, enabling the software to be tested for many geographic locations and scenarios. While many other geodesign projects are built for a unique planning situation, a specific region (Janssen et al. 2014), or are built to use data produced by the US Census (Nedović-Budić et al. 2006), the range of possibilities this software could be used for required reliance on globally available data. The necessity of global data creates a challenge for the development of analysis products as they must rely on globally available data sources.

To facilitate the global acquisition of data, we developed a series and processes of tools called HUB. HUB empowers users to acquire previously validated datasets relevant to their chosen site geography and timeline, then convert and organize it into a mission folder that then the backbone of ENSITE analysis. The acquisition and processing of global datasets for HUB with significantly high temporal and spatial resolution required a combination of creative thinking, thorough vetting, and rigorous testing. Before data can be included in analysis within ENSITE, it must be vetted, a process which includes a literature review and approval by the ENSITE Data Governance Committee. ENSITE draws data from both existing open-source and authoritative Army repositories, such as the National Geospatial-Intelligence Agency and the Army Geospatial Center. After data is approved for inclusion, a workflow was created on how a user will gain access to the data. For some data sources, this can be accomplished through

connecting to an application programming interface (API), while other data sources require filling out a data access request form. Each dataset, and the workflow to access it, are explicitly documented in easy-to-follow steps. Once data is acquired, it is processed through a series of tools to translate the vector data into the ground warfighter geospatial data model (GGDM). As there is no standard for raster naming within the Army, the data is renamed and processed according to schemas specified by the HUB team. To allow for future interoperability between datasets, we have created prefixes for all data. For example, an elevation dataset has the name “DEM\_” while a land cover dataset starts with the prefix “LC”. All of the data is placed into a Mission Folder, a portable series of folders which all data to have consistent paths regardless of the location.

Within Steinitz’ geodesign framework, he stresses the need to answer all the “why” questions, working through the first and second iterative loops of the framework before obtaining any data (Steinitz 2012). To Steinitz, this is critical to ensuring a geodesign project remains decision-driven--not data-driven. As previously stated within the introduction, the ENSITE team did not follow the Steinitz geodesign framework in developing the ENSITE software in terms of answering all 6 questions in the first two loops of the framework. However, not making data acquisition the first step in any project - including ENSITE - in no way lessens the importance of obtaining accurate, timely, and well-documented datasets suitable to the study goals. The team did ask and answer questions on how ENSITE could change the deployed forces operational environments before establishing what data was needed to do so. This philosophy was further solidified as the application team developed ideas and prototypes using data that worked to answer their research questions, not caring if it was global in scope. However, because of the constraints of using global data, sometimes the availability of data dictates analysis.

Despite defining global data as a crucial component to the ENSITE geodesign framework, global data sets are not sufficient to contextualize the local environment adequately. To plan a base camp, one needs contextual site information such as site soil samples or a site survey. To enable this capacity, ENSITE is interoperable and partnering with ENFIRE. ENFIRE is a technical engineering tool set, designed to generate, manage, analyze, and digitally distribute a wide variety of engineering data to significantly enhance a number of current and future force command and control requirements. The data collected from ENFIRE follows a consistent schema and is therefore easily integrated into analysis within ENSITE.

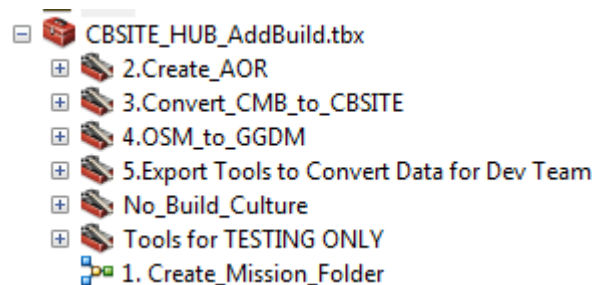


Figure 3 Screenshot of the ArcMap Toolbox for processing data

## Flexible Backend

Using an interface designed and coded internally, ENSITE has been developed with a back end which can process and analyze data with tools written in different languages. The benefit of having a flexible analysis engine is that members of the team can code in a language which they are comfortable with. The programming languages range from R and Python to ArcGIS model builder. This framework component readily illustrates one of the principles of geodesign by increasing collaboration through reducing the barrier to entry.

As a geodesign platform with a flexible back end, ENSITE is able to interface with other technologies such as CAD (Jensen 2011). The sites identified as possible locations for forward deployed infrastructure can be exported to VFOB, an Auto-CAD infrastructure planning tool, where a base camp is designed. The designs from VFOB can then be fed back into ENSITE for further spatial evaluation such as line of sight. The flexible back end further allows for data produced to be shared via ArcSDE on the Reachback Engineer Data Integration (REDi).

## Rapid Development

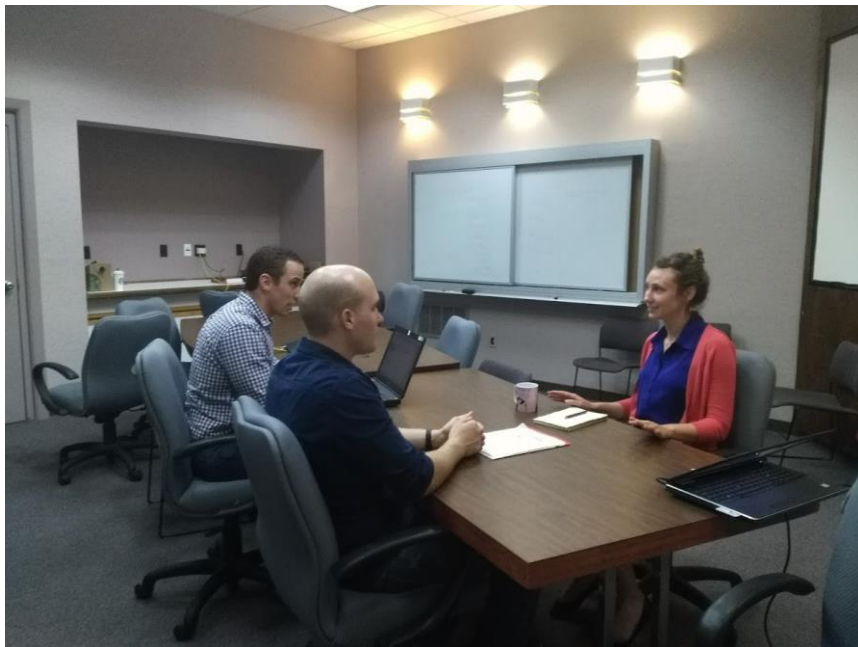


Figure 4 Members of the ENSITE team strategize a new capability within ENSITE

One of the cornerstones of the ENSITE development process is the adoption of rapid development. Rather than spending months or years on a feature before putting it in the hands of future users, we concentrated our efforts on the rapid development of analysis followed by user engagement. Using ArcGIS Runtime for .NET, we were able to develop in a few months' time a geospatial analysis platform prototype. This application then allowed the team to test the idea of having a standalone program, rather than developing a series of tools to be run in a program like ArcMap. Through engagement with potential users, such as members of the 12<sup>th</sup> Geospatial Planning Cell (GPC), the team was able to identify potential issues with our underlying assumptions and workflows, and were alerted to changes that we needed to make.

For example we were storing multiple locations data in one database. Furthermore, our rapid prototyping demonstrated that we needed to have greater control over our user interface and data processing, leading us to move towards creating a custom user interface using leaflet.js. The agile development process allowed us to make these crucial pivots.

The ENSITE team also applied rapid development principles to the analysis capabilities (plug-ins). For each plug-in, a rapid prototype was developed using the coding language that the developer was the most comfortable with—often ESRI Model Builder, but in some instances R or Python. This rapid development process was led by the following structure:

**Step 1. Conceptualize, Research, and Design.** All the plug-ins featured in ENSITE were originally identified as necessary capabilities from an end user community. Through interactions with Army stakeholders, ENSITE developers identify a necessary capability, perform the necessary research, and produce a conceptual design for the plug-in. It is important to note that research is a key component to each capability. Members of the team conduct initial research on a capacity and develop an approach towards solving it. This is an iterative process, so a team member may come develop an initial less complicated solution first and then go into a more nuanced solution at a later date.

**Step 2. Write Code.** The analytical capabilities are then coded to test the concept and its assumptions. This code is written on the platform where the developer has the greatest knowledge and expertise. When developing analytical capabilities, developers must write the code to be compatible with the capabilities of ENSITE core software. They must also test the code using sample datasets for quality assurance with both the Data and Development teams. This is often characterized as an iterative testing and debugging phase.

**Step 3. Integrate with ENSITE Software.** After an individual plug-in developer finishes his/her code and has tested it on sample datasets to ensure the accuracy of the processes, the next step is to fully integrate it within the core-software and perform quality control. The Core-Software Team handles majority of the integration, but it is the responsibility of the developer to ensure the analyses meet user expectations.

**Step 4. Document.** Developers are expected to provide a minimum amount of documentation directly in the code. Additionally, the developer works with the documentation coordinator to maintain accurate records of workflow steps 1-3. These records not only serve as metadata, but also feed program briefings and technical reports.

## **Team of Subject Matter Experts**

One of the more distinctive qualities of the ENSITE team is its core composition of subject matter experts. The ENSITE team comprises over forty individuals representing diverse fields such as Community Planning, Forestry, Structural Engineering, and Geography. There is a recognition on the team that no one is able to complete the tasks themselves, which creates a joint ownership in the end product (Brown, 2009). Simon recognizes this too, discussing the



importance of establishing a foundational base for “intellectual endeavor and communication across the arts, sciences and technology” (Cross, 2007). Conscientious and purposeful collaboration is core to geodesign-- be it through “multi-person teams” (Ervin 2013) or “collaboration” (Kumar, 2012; Steinitz, 2012). Planner Paul Zwick (2010) specifies one of his criteria for geodesign is that the process “integrate the design professions with other disciplines—ecology, geography and other earth sciences, real estate, and the social sciences”.

This dependency among team members results in a collaborative work environment and a higher quality production process. Team member diversity has facilitated rapid prototyping, as different individuals have been able to contribute their own unique perspectives and insights into application development while checking assumptions made by others. For example, a Community Planner and Physical Geographer developed a tool for assessing the suitability of land for development by classifying land use types. Their assessment was based on urban planning principles. However, feedback provided by a structural engineer highlighted an incorrect assumption in their work (Foster 2016). Perhaps the most obvious example of the benefits of geodesign (i.e. bringing together science and design) is the ENSITE UI/UX sub-team. The design and development of the user interface and experiences (UI/UX) for ENSITE involved collaborative brainstorming, sketching, and storyboarding sessions between computer scientists, geographers, geoscientists, graphic designers, and anthropologists; not one of whom would be considered an expert in user experience, but all of whom had useful contributions to how our user community could easily flow through the program.

The deference to and incorporation of SME moved beyond the internal workings of the ENSITE team into the larger ERDC and Army organizations through frequent user testing and program demonstrations. Socratically acknowledging the need for input from the deployed forces user community, the ENSITE team attempted to engage former warfighters and enlisted service members to run through all aspects of the ENSITE software, including HUB and Analyst. This was supplemented by internal user testing of our integration partner products, such as ENFIRE and VFOB. This ability to easily deliver a demonstrable, functioning prototype into the hands of superiors and current Army soldiers/officers is a direct result of the previous three core geodesign framework components.

## Conclusion

The ENSITE project is novel, both as a product and as a process, both for the US Army and for the broader GIS defense solutions community. The four-part geodesign framework created and utilized by the ENSITE team has allowed the project to set, meet, and exceed goals within mere months of project kickoff. As of July 2017, ENSITE has developed eight versions of the software, conducted over a dozen user engagement sessions, and partnered with two other major army software development programs for deployed forces. Without even one of the four core components of the ENSITE geodesign the framework, the project would have been unable to succeed.

## References

- Brown, Tim. 2009. *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation*. Harper Collins.
- Ervin, Stephen M. 2013. "What Makes It 'geodesign'?" *The Field*. August 22. <https://thefield.asla.org/2013/08/22/what-makes-it-geodesign/>.
- Flaxman, Michael. 2009. "Fundamentals of Geodesign." In . [http://www.kolleg.loel.hs-anhalt.de/landschaftsinformatik/fileadmin/user\\_upload/\\_temp\\_/2010/Proceedings/Buhmann\\_28-41.pdf](http://www.kolleg.loel.hs-anhalt.de/landschaftsinformatik/fileadmin/user_upload/_temp_/2010/Proceedings/Buhmann_28-41.pdf).
- Foster, Kelleann. 2016. "Geodesign Parsed: Placing It within the Rubric of Recognized Design Theories." *Landscape and Urban Planning* 156: 92–100.
- Goodchild, Michael F. 2010. "Towards Geodesign: Repurposing Cartography and GIS?" *Cartographic Perspectives*, no. 66: 7–22.
- Janssen, Ron, Tessa Eikelboom, Jos Verhoeven, and Karlijn Brouns. 2014. "Using Geodesign to Develop a Spatial Adaptation Strategy for Friesland." In *GeoJournal Library*, 103–16.
- Jensen, Meika. 2011. "What Is Geodesign? ~ GIS Lounge." *GIS Lounge*. September 30. <https://www.gislounge.com/what-is-geodesign/>.
- Miller, William R. 2012. "Introducing Geodesign: The Concept." ESRI. <https://www.esri.com/library/whitepapers/pdfs/introducing-geodesign.pdf>.
- Nedović-Budić, Zorica, Raymond G. Kan, Douglas M. Johnston, Richard E. Sparks, and David C. White. 2006. "CommunityViz-Based Prototype Model for Assessing Development Impacts in a Naturalized Floodplain—EmiquonViz." *Journal of Urban Planning and Development* 132 (4): 201–10.
- Steinitz, Carl. 2012. *A Framework for Geodesign: Changing Geography by Design*. Esri Press.
- Tess Canfield, Carl Steinitz. 2014. "Geodesign." presented at the 4th Geodesign Summit, Redlands, California.