

Composites: A Maze of Twisty Passages, None Alike

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Abstract

A study of software, the way it materializes perspectives, and the limits of the promulgations of those perspectives.

Composites: A Maze of Twisty Passages, None Alike

It's Software's World, We Just Live in it

Software is now well represented in every nook and cranny of the world. Though this project directly engages software, software was also used at every stage of its production: conception, composition, distribution and (in the age of covid-19) discussion. In the same moment that our reliance on software reaches ever loftier heights, we are surrounded by stories of important pieces of software being biased against vulnerable groups. Standpoint theory suggests that such biases often come from the hidden and unacknowledged perspectives of the people making software (Haraway, 1988; Harding, 1992). In this sense, the problems caused by bias in software are not new problems. But, as Mackenzie (2006) and Kitchin and Dodge (2011) have noted, the management of a software project is filled with the work of managing relationships. Relationships between technical components, the humans doing the work and everyone's expectations about the future. Software also exists within ecosystems: code written for a particular Software-Artifact is surrounded and supported by code that many other Software-Artifacts rely upon. The impact of the final Software-Artifact reflects the intent of both the organization producing that Software-Artifact and the diffuse intent of the surrounding soft/hard/ware ecosystem. Software interventions into existing projects can highlight the paths of agency within software-artifacts. What can we learn about effecting change in software by studying how agency is mediated by the assembly process?

Software-Artifacts are the result of an assembly process that brings together the source code from many different software projects. Each Software-Artifact is what Latour and Centre de Sociologie de L'Innovation Bruno Latour (1999) called a "blackbox" - a container that hides complexity. But in order to properly describe software, I needed to expand the idea of a blackbox. In Latour's theory, each blackbox contains other blackboxes with clean separations between those layers (Latour & Centre de Sociologie de L'Innovation Bruno Latour, 1999, p. 183). Software blackboxes, however, often interact across blackbox boundaries. A Software-Artifact will use one library as a clean blackbox but interact directly with the inner-workings of another library. Exactly which pieces of code drive particular behaviors in a given software artifact is difficult to predict in advance and working backwards from artifact behavior to code identification is not straightforward. This is because a Software-Artifact is a Composite - a heterogeneous mix of elements where the role of each element in any given Software-Artifact is determined by the rules of the particular assembly process used to create it and whose component parts cannot be broken apart. This means that users and developers experience things in fundamentally different ways. Where users are always interacting with Composites, whose various component pieces cannot be differentiated within the Composite, developers are always interacting with pre-assembly components. This is because changing composites directly is inefficient, so modern software development process relies on making changes to components before one or more assembly process(es). These components are where engineers leave imprints of their views. However, understanding how those views coe to the surface of Composites depends on examining the assembly process that creates each given Composite. The path of each materialized perspective through various assembly processes is unique.

Returning to the question of what one can do to address perspectives in software, this project takes the Free Open Source Software (FOSS) project Emergency

Development ENvironment (EDEN) as its object of study and site of intervention. I chose EDEN because it is, as far as I can tell, a well-made piece of software that fulfills its role in the world. Others will engage socially problematic software and try to fix it, but the goal of my work here is to engage with a piece of software which is not obviously harmed by the standpoints of its developers. This does not aim to be a critical engagement, but an engagement whose successes and failures may be informative for future critical projects. The result of the modifications to EDEN can be seen at www.edenproject.org. The changes to EDEN highlight where EDEN crosses blackbox boundaries, though my efficacy in making those crossings apparent is limited to particular *kinds* of boundaries. As we will discuss, software is deeply heterogeneous and that heterogeneity impacts the work that is needed to engage with it.

What can we Say about Software?

The Social World of Software Makers

A great deal of excellent sociological work has been done on communities that produce various kinds of software. The communities that have been studied often have particular qualities of their social structures connected to their shared work of creating, maintaining and promoting software (Kelty, 2008). Other work has focused less on the work of making software per-se and has instead highlighted how ideas of freedom, creativity and openness (of a particular kind) attract people to communities that make software (Gabriella Coleman, 2012). These ethnographic engagements with communities that produce software share a perspective that certain kinds of social structures are better suited for producing software (in general) and *certain kinds of software in particular*. The FOSS movement, Kelty claims, has a social structure that flows directly from the ethics of sharing and attribution that unite the software projects under the FOSS banner (Kelty, 2008). While there are important lacuna in Kelty (2008)'s somewhat utopian descriptions of FOSS communities, especially for non-male and culturally heterogeneous people, it seems true that social structure and technical goals co-create and co-evolve with each other (Dean, 2010; Penny, 2013). Similar conclusions are reached by Boellstorff (2015) when looking at online cultures and Ensmenger (2012) in his study of the history of the profession of computer programming. Boellstorff (2015) vividly shows the validity of considering people spending in time in digital spaces *isolated from* any actual world¹ referents. He freely notes relationships between the accounts his interlocutors give of their actual world activities, but understands that it's still valid to engage with those representations directly without trying to prove any truth-claims about them. Ensmenger (2012)'s work is historical rather than ethnographic, but also supports the ways in which the material demands of making software created social structures that have endured until today. There are consistent links between the nature of the virtual and the social structure of the actual people who create digital products, but each of those qualities can be examined independently

¹ Boellstorff (2015) rejects the idea that events in digital spaces (like games or chat rooms) are any less "real" than things that exist in the physical world and thus rejects the common language of "real" and "virtual." He instead talks about "actual" (physical) spaces and "virtual" (within digital worlds) spaces. I will be describing the physical world as the "actual" world when appropriate and will talk about both virtual space (space that fully exist in computers such as Second Life and World of Warcraft) and digital space (spaces that are displayed through digital mediums, but are constituted of a mix of real and generated media [facebook, instagram]). It is all "real."

without needing to fully understand the nature of the links. Gabriella Coleman (2012)'s focus, in particular, on "hacking" cultures that exist outside of any particular culture of "software" or "code" points to these social structures fitting particularly well with software, but not proceeding directly from software per-se (Drexler, 2019). This is in line with Cox and McLean (2013)'s examination of the expressive qualities of "coding" (which may or may not be a synonym for "software") and how they relate to the long history of speech as well as how the particular material qualities of computers open up new avenues for expression. For this project, these works suggest that EDEN does have a particular culture around it, especially because EDEN's makers (the Sahana Foundation) places the project within the FOSS world of software development and the Information and Communication Technologies for Development (ICT4D) world. Studying this particular social situation would doubtless be productive work and continue the conversation around the social character of collectives that create software and try to promote FOSS ideas in particular historical, economic and legal regimes. However, this work also suggests that while the a particular Software-Object and the culture around and within that Software-Object co-create and drive each other's evolution, they also suggest that either can be considered in isolation at a particular moment in time. Indeed, Kelty (2008) and Gabriella Coleman (2012)'s observations both depend on connecting independently observed qualities of *culture* and *particular FOSS projects* in order to draw out the co-constitutive qualities. This project leaves whatever co-constitutive cultural links that exist between EDEN and the people and cultures that produce it to others, though I am quite sure interesting work exists there.

The Social World Software Helps Construct for Us

Even without a direct ethnographic engagement with the team working on EDEN (or its users), previous work on software and its effect on the world has been useful for guiding the focus of this project. It goes too far to say that the nature of socializing has been transformed by digital networked communication, but society (and social scientists) are engaged in an ongoing effort to sort out truly new ways of using media and new forms for existing modes of socialization. Much of this work has focused on modern, media-focused ways of keeping socially connected with people (Humphreys, 2018; Jurgenson, 2019; Tiidenberg, 2018). This work is not about making software, but speaks to the power *of* software to structure and channel social activities. Like the social structures that exist around the act of making software, living with software pushes us to act in particular ways. Humphreys (2018) both highlights how modern practices of using global digital networks to keep in touch with each other proceed directly from more localized historical practices, and how the way we represent ourselves in digital spaces reflect possible social realities that only exist in those spaces. Software places is in new social configurations: a neighbor I have never met could see my vacation photos without asking me, I bring my assumptions developed over a career of software development for US software startups to my review of an internationally focused (but originally Indonesian) system for disaster management. Though each digital connection has a particular character and the field is difficult to tantalize accurately, many of the connections that have become more common bridge greater social distances than previously possible. Dean (2010) highlights this quality of digital spaces when she speaks about the collapse of predictability in how others will see us. The accessibility of digital spaces means that we may be famous "online" but anonymous in person, or visa-versa.

Software Today

How to think about software

The object of study

EDEN

The particular piece of software this project studies is Emergency Development ENvironment. EDEN was originally created by a coalition of Sri Lankan Information and Communications Technology companies in the wake of the 2004 Indian Ocean Earthquake and Tsunami. The project is now managed by the nonprofit Sahana Foundation. It has been used in numerous disaster responses since 2004 and is also used by a number of organizations for managing resources outside of any specific disaster (Sahana Foundation, n.d.). EDEN's functionality can fairly be described as tracking and managing resources. Its power comes from the enormous range and detail of the information it knows how to track. EDEN has indexes for organizations, people, projects, events, facilities, supplies, documents, possible scenarios, and events. It also provides on-platform messaging and special tools for the management of emergency shelters (Sahana Foundation, 2011). Each resource is meant to be connected to other resources: people work for organizations, projects are run by organizations and are associated with people, facilities are linked with projects and organizations and other resources like supplies and verticals. The flexibility of the software means that it can be used to manage a single organization, multiple organization, or used as a hub for many different groups coordinating around shared goals but without central authority. The system aims to be as comprehensive as possible and to use the same entity for resource and system management. The entries for people can act as a simple rolodex and will also double, if desired, as that person's account within EDEN. The interface for managing goods is the same interface for managing access to the management system. To the degree possible, EDEN is structured to allow the same people who do the day-to-day work of the organization to administer the system that manages the organizations' resources. It also aims to be an effective tool for people at all levels: administrators can track where people and supplies are allocated and volunteers can access their assignments, documents and information about how to use resources.

Why EDEN

I selected EDEN for this project for two primary reasons: it is a Free Open Source Software software project in a language I am familiar with and it is not obviously problematic. I will detail its open source pedigree shortly, but first I want to explain my second selection criteria. "Improving" software (whatever improving means) can usefully be separated into at least two questions: what quality should change and how do you bring that change about? This project attempts only to speak about the second (likely easier) question. Partially this is because the project was designed to fit within the confines of a final project for a masters degree. This project represents, roughly, three graduate level classes worth of work. I didn't feel like I had time to find *and* fix flaws. So this project should be understood as neutral on the question of, "is EDEN good?" Nothing about EDEN seems bad to me. They have received numerous awards, glowing testimonials, and are used by many large organizations that could use other products if EDEN were lacking.

I lack the experience and expertise to say that I think EDEN is *good*. Assessing if software is "good" or "bad" is not straightforward. Simply examining Software-Artifacts in isolation tell us very little. It's only through engaging with one or more Software-Artifact(s) as they exist in the lived world and contextualizing that with detailed ethnographic work that it's possible to start making value judgments (Eubanks, 2018; Schüll, 2012). Those judgments wouldn't be universal, of course, but would be about a particular population. So this paper is done from the perspective that EDEN seems fine to me. The project is interested in the technical details of how the EDEN Software-Artifact emerges out of its Software-Object and how agency is modified by that process.

Finally, and briefly, this project does not take the position that the technical qualities it investigates are free from the impact of social structures. Gabriella Coleman (2012) and Kelty (2008) have both compellingly shown that the social and technical co-produce each other. However, we can still usefully speak about qualities that technical systems have and how those qualities impact our lived experience. That this project has obvious extensions in the social and ethnographic realm is a strength and declining to investigate them should be understood as a concession to time.

Out of Many, One

Wherever possible, EDEN uses FOSS technologies. The language it is written in, the libraries it relies on to provide functionality, the tools it uses to support its functionality, and its main operating system are all both open source and available at no cost. EDEN will generally operate on top of non-FOSS systems like Microsoft Windows, but the team doesn't prioritize systems outside of the FOSS systems they develop and test on (Sahana Foundation, 2015). Kelty (2008) talks about how FOSS is both a philosophy and a system of development that has practical impacts. One of the side effects of EDEN committing to use the FOSS ecosystem is it makes my form of engagement possible. Though it is possible to examine compiled machine code and draw some conclusions about the intent and process that assembled it, such a project would be far outside my capabilities. Instead, the source code of EDEN, web2py (the web framework EDEN uses), Python (the language EDEN and web2py are written in) and all of the libraries used by the project are open source. Their preferred databases (MySQL or PostgreSQL) are also fully open source projects. Open source projects often don't just publish the current source code, but offer full histories of what change, when it changed, who changed it and how it was changed. These changes often include notes about why *that particular* change was made over any other possible change (Chacon & Straub, 2014, p. 13-16). Open source projects also commonly have systems for tracking lists of unfixed flaws as well as planned future improvements (both types of Mackenzie (2006) relationships), but those systems operate above the layer of source code so this project does not engage with them.

Investigating EDEN

My work began, as all software work does, with work of assembling the components that transform EDEN from a collection of python source files into a Software-Artifact. This requires connecting a number of components together: libraries and tools in the glspython language and a wider set of heterogeneous tools (databases, non-python libraries and tools). Some of these components remain as source code to be

interpreted by python, some of them are downloaded as source code and go through their own assembly process to generate their own Software-Artifacts. The assembly process that draws the components of EDEN together does not happen in a single step, but is a number of loosely ordered heterogeneous processes. Some must be completed before others and there is an officially recommended order in which to prepare the various components, but often these orders are more matters of preference than necessity. What is important is that all of the required components are collected in their expected places by the time EDEN itself is run.

The Sahana Foundation recommends that developers use a Virtual Machine that has EDEN and its supporting libraries installed through a script. However, at the time that I engaged with the project, the instructions for how to install EDEN focused on using operating systems and python versions that have since stopped being updated². Though more modern scripts can be found, the standard install scripts for the EDEN Virtual Machine and the script to install the software on a physical machine both use operating systems released in the mid-2010s that have not been maintained for at least 5 years (Canonical, 2020). However, EDEN is aware that this is problematic and makes an effort to support newer versions of python and newer operating systems, but official instructions to use the latest software are sparse.

Choosing to offer a fixed and unusually old set of tools is the first materialized I found encoded into EDEN³. The state of the scripts reflect a culturally important choice. The team could note and situate their approach in their documentation, but they have not. However, project-wise choices to use older or newer versions of tools are common. There are software projects (sometimes entire programming languages) that greatly value using the most up to date version of a tool or library (Fernandes da Costa, 2017). These communities have legitimate fear that older versions of tools are examined less often and will likely be fixed less frequently. They feel that using the latest (within

² As Mackenzie (2006) points out, software is a process not a thing. This is especially true for software like EDEN, which is made available to users over network connections. Pieces of software that stop receiving updates can quickly become vulnerable to new interactions with an ever-changing ecosystem. These vulnerabilities can result in programs becoming unstable, new security vulnerabilities, or simply an inability to keep up with the changes to other components. Software that is no longer being "maintained" (the phrase used to describe engineering work to patch security holes, update interfaces to modern standards, and make those updates generally available) can suddenly stop working because one or elements of its ecosystem cuts off old software. It is true that isolated software can run for years or decades without changes and that, for some systems, users never experience adverse consequences for leaving them frozen in time. However, whether or not a program can "safely" be left alone is highly dependent on external factors and software that seems "safe" from needing changes can suddenly and tragically need emergency updates at high cost (Lee, 2020).

³ It's a fair question to ask where EDEN begins and ends. Certainly its source code is part of the program, but I would also include the collected documentation on how that source code should be deployed and supported as part of the "program," even though it's not actively involved in the functioning of an assembled Software-Artifact. This is best understood with Star and Griesemer (1989)'s idea of boundary objects - coordinating objects that are able to play multiple roles for different actors. The Software-Artifact of EDEN cannot exist for anyone outside of its immediate development team without distributing instructions on how to assemble the Software-Artifact, so I include that material in the EDEN boundary object. It's worth noting that many of the requests for help with EDEN on the Sahana Foundation mailing list are questions not about EDEN per-se, but about the tools and libraries that support a fully functioning EDEN. In a very real sense, the EDEN that exists without instructions on how to assemble it isn't available to me: I wouldn't know how to access it.

reason) version is a goodness in of itself⁴. If the EDEN team followed this philosophy, they would not default to using older operating systems and versions of python. They would need to watch their ecosystem of tools and libraries more closely, but the versions they were watching would also be more in the collective consciousness of the FOSS world.

All this isn't to say that the EDEN team choice isn't a sensible one. The latest versions of tools often lose track of the world outside the top of the capitalist pyramid. The same networks of power that structure the spread of physical technology also shape the attention of active software engineers. EDEN has chosen to use established and well-supported versions of their tools⁵. Their older set of tools is more likely to have undiscovered (or unpatched) security vulnerabilities, but they are virtually certain to function properly and immediately allow the successful assembly of an EDEN Software-Artifact. That set of probabilities seems very well suited to the expected audience for individuals first setting up their own copies of EDEN: individual developers setting the system up to better understand it. When another team decides to deploy their own copy of EDEN in a way that's available to the public, they can assemble that Software-Artifact using a balance of newness and stability that feels comfortable to them⁶.

Investigating Assembly

It's one thing to identify where the EDEN install scripts sit in a cultural gradient. It's another to engage the particular choices that the EDEN project has made. I chose to install a far newer set of tools, based on the projects newest recommendations for new installs (König, 2019a). I was guided by the python 2.7 installation script provided on the Sahana EDEN wiki⁷. However, I chose to use a version of python originally released in 2016 (six years after the default version used by EDEN). Using a newer version of python seemed like a sensible software engineering choice and also a way to check if EDEN was, as they claim, able to operate equally well on the version I selected (3.6.9) and the 2.7 version that EDEN uses by default⁸.

⁴ A language has evolved to speak about the relative stability of a particular Software-Artifact (or, more precisely, the boundary object that includes a Software-Artifact and its assembly instructions). Signaling about how often you will be changing your software allow users to choose the version of you work that will fit their own rhythm (Canonical, 2017). 'Unstable' releases are often more likely to have bugs or be insecure, but also have new features that cutting-edge projects may need. 'Stable' releases have few new features but are well understood and unlikely to be the source of problems.

⁵ As of the writing of this paper, the versions of Ubuntu that EDEN installs into by default have left long term support. Though evaluating if that's good or bad is outside the scope of this paper (and my expertise) it seems important to mention it.

⁶ Of course, this update process also has risks. A well known mix of library versions will work together, but as I'll note later, mixing different versions of libraries can cause unexpected dysfunction. Suffice to say that the old versions of the tool and library ecosystem will generate the fewest unexpected tooling problems and maximize for developing in an environment familiar to the EDEN team.

⁷ The Script I used can be found <http://eden.sahanafoundation.org/wiki/InstallationGuidelines/Linux/Server/CherokeePostgreSQL>, though as I describe, I often used different components. Unedited notes on the things I ran into can be found at https://github.com/aeturnum/masters_project/blob/master/Notes/Web2Py_Notes.

⁸ I selected a release from the 3.6.X series because I'm fond of f-strings (a features added in 3.6 that allows compact formatting of printed information). However, 3.6.9 is now actually out of date, as 3.6.10

Selecting a more modern python turned out to have knock-on effects. Some of the libraries that EDEN requires are written only for python 2.7 and replacements were needed to function with 3.6. One of the major changes was that the version of Web2Py the EDEN scripts installs does not support python 3.6 and so I needed to chose an updated version. I selected 2.18.5, but this new combination of the EDEN source code and the Web2Py source code revealed that the two projects had drifted apart in small but essential ways. Specifically, in a section of the Web2Py and EDEN code that handled data validation.

Data validation is, in general, the work of verifying that information conforms to a set of standards and informing the user how it has failed to conform when a problem is found. This should always be performed any time data is stored in a system. Digital storage systems have expectations that, when violated, can cause immediate systems failures. Web frameworks commonly provide facilities for verifying data and Web2Py is no exception. Web2Py has components that will check that that user input can be converted to numbers or dates or email addresses, among others. Web2Py is open source and so all of that functionality can be expanded by programs that make use of Web2Py and EDEN does so in a number of places.

In between the version of Web2Py that EDEN uses by default and the version of Web2Py that I selected, the control flow of data validation has changed slightly. This change meant that custom data validation classes that were written using the older Web2Py system no longer fit into the expected control flow of data validation. The EDEN data validation code, based on the older standard, is not called properly when using the newer version of Web2Py. This doesn't stop the successful assembly of an EDEN Software-Artifact, but once that Software-Artifact is assembled most of its functionality is inaccessible because the EDEN-specific data validation code won't run and so the system won't accept that data.

This problem is interesting because it turns out it captures a moment in time between the Web2Py team and the teams that use Web2Py (i.e. EDEN). If I had selected a slightly earlier version of Web2Py, then it would have used the old system and the EDEN code would remain functional. Web2Py immediately realized the problem and accepted a fix⁹ for the issue. This is exactly what Mackenzie (2006) describes when talking about the management of relationships between software components. The Web2Py successfully implemented a new way of handling data validation control flow, but they neglected that they were doing it in such a way as to break an existing relationship they did not mean to break. Because I happened to select a version of Web2Py that was temporarily out of relation with EDEN, I failed to assemble a fully functional Software-Artifact. This got me interested in assembly.

was released just a few days before the end of 2019 (Python Software Foundation, 2019). In a perfect world I would have used 3.6.10, but as this project includes no private information I stuck to 3.6.9.

⁹ Interestingly enough, the problem was fixed by a piece of code written by a member of the EDEN team (König, 2019b). The Web2Py team had already noticed the problem and thought they had fixed it, but their fix did not work for for all circumstances and required more work.

Investigating Assembly

Glossary

Composite A Latour and Centre de Sociologie de L’Innovation Bruno Latour (1999)ian black box whose functionality cannot be reduced to a blackbox containing other blackboxes. Instead, a composite is a network of blackboxes are heterogeneously linked. In addition, where the contents of a blackbox become socially visible when the blackbox stops working, composites can totally fail and remain opaque.. 3

python Python is an open source, interpreted, high-level, general-purpose programming language. It was initially released in the early 1990s, but has been continuously updated since then. Python 2 was the standard from 2000 to 2008, but in 2008 Python 3 was released with backwards-incompatible changes. This split the Python community, leading to Python 2 and Python 3 having slightly different versions of tools available. Python 2 continued to receive support and updates until 2020, when official support for Python ended (Wikipedia contributors, 2020). The open source nature of Python means that it is likely that Python 2 will continue to be updated by users after official support ends. . 7, 8, 9, 10

Sahana Foundation The nonprofit that manages the EDEN project. Based in Los Angeles with an international scope and focuses on supporting communities in disaster preparedness and response through information technology.. 5, 6, 8

Software-Object A generic term that describes the entire process that leads to the production of a series (or a single) software artifact. This includes the economic and cultural position of the organizing project, the social organization of those who write the code for the piece of software, the social positions of the software artifacts’ users, and the software artifacts themselves. This term is used in opposition to the common "software" because of the potential confusion between a "software project" (the organizing structure of a Software-Object), a "program" (a Software-Artifact), and other linguistically confusing ways of speaking about the multi-layered process that produces "software.". 5, 7

Software-Artifact An entity of uncertain composition that behaves, for common users (as opposed to technical staff) as a single entity. A software-artifact could be a single binary with all its functionality provided by machine code included in that single location in memory. It could also be a binary that makes calls to various libraries. In the case of EDEN, it’s an expensive set of Python files - some of which are human readable and some of which have been modified to make them faster to read. In this case a separate program, the Python binary itself, reads and executes the EDEN program. Even though EDEN is many separate files and contains no machine code, it is properly considered a software-artifact because users interact with it as a single entity. Software-artifacts are produced periodically by software projects, but are not themselves entirely "software." The idea of software must be large enough to allow multiple software-artifacts to exist within the same project: the current version of your phone OS and the next version, the Facebook app on your phone and the web server that tells it what has

happened. Nevertheless, when we are using "software" we are always directly interacting with one or more software-artifact(s). They are the material reality of software projects.. 3, 7, 8, 9, 10

Virtual Machine A family of packaging techniques that allow packaging and distribution of an entire computing environment (operating system, libraries, programs) in a single digital object. This allows one physical computer to run several independent "machines" simultaneously. When a virtual machine is started, it the hardware it sees is virtual hardware simulated by the program "hosting" the virtual machine. The hosting program then translates requests to that virtual hardware into requests to the real hardware and relays the responses. Running a program in a virtual machine is slightly less efficient than running it on real hardware, but this cost is often less than the cost of manually arranging non-virtual installs on real machines.. 8

Web2Py An open source web framework for Python 2.7 and 3+.. 10

web framework A heterogeneous set of software that allow a programmer to efficiently write and manage providing a service over the Internet. This could be a website or a mobile app (often it is both) or a go-between for other services. Examples include web2py and Django in Python or Phoenix in Elixir.. 7

Acronyms

EDEN Emergency Development ENvironment. 3, 4, 5, 6, 7, 8, 9, 10

FOSS Free Open Source Software. 3, 4, 5, 6, 7, 9

ICT Information and Communications Technology. 6

ICT4D Information and Communication Technologies for Development. 5

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