Appendix

A sample quote pertaining to a subsection of the results is provided. For each quote, we note which sub-sample group the interviewee was categorized as (Framework, Database, or Middleware).

3.1.1. Governance is intentionally created

Framework project: "*if you claim to be a community organization the community itself has to have a means of participating in this governance, it is not a passive thing*"

Database project: "*A big pitfall [of the project] was the governance model. I think what we should have done – what NSF should have funded - would have been a director of that facility to govern*"

Database project: "*We had a sort of turnover in 2012-2013. The whole leadership got sort of scrapped and reformed in a different way, and the executive committee now takes on more of a policy role because the system was "done".*"

Framework project: "**...***it was really important if this thing was going to be sustained that there be a transfer of a fully open voting procedure where people could elect their next members*"

Framework project: "...*you're all at the same table, so it's not like you get more say than the startup that just joined.*"

3.1.3. Top-down and bottom-up governance is balanced

Database project: "*It was an extremely healthy mixture of both of those models that– clearly at the corporate level–I and program managers were responsible for…a lot of the putting forward of ideas developing initial budgets. But it was then a process of going through and making sure that those withstood the review of the community. And it wasn't until they had the approval of the community that they went forward.*"

Framework project: "*For people to have a sense of ownership, they need to feel a part of it*"

Database project: *"[the community members] weren't involved in the decisions; they contributed to opinions."*

3.1.4. Leadership qualities are considered based on project needs and community representation

Framework project: **"** *if that one head is very powerful and can raise money like this, then there's real trade offs there, because…[do] you get a powerhouse who can just write checks or do you try to make it into something which is [community] owned?***"**

Database project: "*I've learned quite a bit from people who are project managers, but …I really haven't learned anything that's useful about how you manage people who want to be independent.*"

Database project: "*[Co-manager] and I co-manage basically everything. I'm more of the science-based needs, and he's more of the technical. But we pretty much make decisions together on just about everything.*"

Framework project: "*a lot of people think that these board memberships are sort of honorary titles that they get to put on…they're going to show up once a month and give their advice but I personally believe…that if you are on the board of these types of organizations then, just like in a company…you're not passively giving your opinion to other people who are going to run it. You are supposed to be running it…you take on…an active role in ensuring the long term sustainability of the organization…*"

Framework project: "*It was kind of at a clash with this idea of what we're going to just elect everybody that we want to the board. And yes, we want to bring in people from underrepresented countries and we want to bring in junior people and we want*

*students, but they're not going to be able to devote themselves to fundraising in the same way that it is when you have a senior perso*n."

Framework project: "...*the sign of a healthy organization is one where participation is not the same five people every single time.*"

3.1.5. Leadership succession plans is a part of project sustainability

Framework project: "...*[sustainability also means] you have the processes in place to deal with the fact of what happens if your executive director director quits*"

Database project: "*We've tended to have two technical people in data management on the award, but also two core scientists…*"

3.2.1. Projects benefit from stewarding and interacting with a community

Framework project: "...*because their missions are big you need as much credibility and as much lowering the risk as possible and that's why they go back to: let's work with the community of experts so I make sure that my positioning is accurate*"

3.2.2. Intentional strategies are needed for community outreach and enhancing participation

Database project: "*What has been really important in the sustainability aspect is that on-going community support, which is only achieved by constantly being in the community, listening to the users, being responsive to the users, talking their language, and being present.*"

Database project: "*I always tell people like don't join the database and don't put data in for the good of the community. Forget that. Do it for enlightened self interest, which is that you want the data in the system and you're going to do something with it.*"

Database project: "*There's a big difference between institutions asking [to] please send me all your data so I can put it in my data archive. As opposed to [a project] on behalf of this hundred member consortium asking you to provide your data through a community resource…*"

Middleware project: *There are a lot of people out there who would like to volunteer, and we always say we encourage contributions. But when I look at how, for example, Mozilla or Apache, and how other organizations do it. They are far better organized to support*

volunteers–to help them understand how to do things, to figure out how to reward them, to figure out how to…help them understand the standards and the processes…It takes a certain type of person and talent [to engage the user community]..."

3.3.1 Sustainability is associated with providing an essential service

Middleware project: "...*it was almost like a utility that you plug it into the wall, and people really just expect it to be there.*"

Middleware project: "...*software that's most sustainable tends to be that which is built around abstractions that can adapt in such a way that they can be applied to problems the designers didn't think of originally*"

Middleware project: "**...***the quality of what you want to sustain…has to be something that's worth sustaining.***"**

3.3.3 Measuring project success is often challenging

Middleware project: "...*we don't really know how many of the servers are out there, we have looked into different ways of trying to gather this information. And in general, there's pretty strong pushback from the data provider community that collecting that sort of information would be a privacy violation.*"

3.4 Business models

Middleware project: *"We transitioned from that academic-hosted project to a nonprofit organization. [W]e were attempting to fund new developments of the technology by funding science, and it didn't really work. So he decided to split the two and leave the scientific work at the University... it felt like we were undercutting the [funded] scientific work to keep the technology funded, and we weren't even able necessarily to push the technology forward."*

Middleware project: *"We decided to spin off from the university and create a company, and we wanted it to be a nonprofit because we wanted to be mission-driven. I had had experiences with companies that had left universities with some technology, and their whole mission was to support that technology. and within a year or two they were doing something completely different, because that's where the money was."*

Middleware project: *"At some point in the program...the funding of it was moved from the…grants program into the…facilities program, because it began to be seen as a facility. And...that really gets to the sustainability point that the NSF, encouraged by its own community of universities, and even its own community of grant recipients could see that to have a healthy…program was actually beneficial to [NSF]."*

Database project: *"...it would not be an institution-based facility, it would not be a data management system on university campus, it would be something, independent of university influences. I think that made an enormous difference…"*

Database project: *"...eventually [it] got too hard because the office was doing too many things, the staff was too big and then there was a very messy transition where I...put in place a leadership team and they would manage staff and then I got further and further removed and that became less fun."*

Database project: *"Ultimately moving to become a facility was making things more expensive, because the overhead that was required for all the reporting or the management of the cooperative agreement, plus the coordination–the additional need to coordinate between all these different projects–was a substantial burden on the budget. I think we have demonstrated now after [the] split up that we're doing better. We are more streamlined in the operation of these facilities."*

3.4.2 Staffing the organization

Middleware project: *"We were actually fairly deliberate about not drawing hard boundaries...and almost every...software developer at some point was involved in user training programs."*

Database project: *"... [the technical people] are the only people paid. The executive committee are essentially volunteers, they all have some other job."*

Middleware project: "*You know we had to let two people go a month ago, because our revenues are down. And there goes all that knowledge that they built up over the years.*"

Database project: *"We've always hired really interesting people, and really interesting people only stay as long as the work is really interesting."*

Middleware project: *"I was surrounded by people who were involved in building various kinds of software building blocks."*

3.4.3 Partnerships often strengthen projects

Database project: *"But I would say it's probably a quarter or less of our overall budget that we get through these side projects."*

3.4.4 Funding Models

3.4.4.1 Grant funding

Middleware project: *"...the development of the system using those grants…took about 10 years to actually get the system going."*

Framework project: *"NIH will keep funding you, and I said, oh yeah I know they will. But I don't want them to, right? I actually want to think about this because…sustainability of these digital infrastructures is a real issue…"*

Database project: *[W]e have...close connections with our program managers to find out what their needs are from the perspective of a funder. But then we also work really closely with the research community."*

3.4.4.2 Alternatives to grant funding

Database project: *"I've tried and I cannot find any [foundations] that seem aligned with what we want to do."*

3.4.4.3 In-kind support

Middleware project: *"But you can imagine that an untenured faculty member would never have been able to do this."*

Database project: *"[Collaboration with other projects is] a feature we offer. How can I put this? Nothing we do generates money. So sustainability is all about the will to do it,*

and the money to do it. We got the will. People are very dedicated to this but it's the money that is what's problematic."

Database project: *"it's not just the money…it's the management structures and they are a little unique to academia…you cannot port a business model–a business structure–into academia with great ease"*

3.4.5 Funding and Uncertainty

Middleware project: *"We were fortunate when we spun off that a hedge fund came to us and wanted to use [the project's software], and they didn't want us to work with anybody else...so they paid us very well.*

Database project: *"I don't remember a year where we had enough money to pay the salaries at the end of the year…in the first five years. So you know, that was a little nerve wracking–that's still true".*

3.4.6 Value-Proposition

3.4.6.1 Interoperability

Middleware project: *"The idea was to take previously developed data systems...and devise some way that they can be combined together to create a system that could represent [different types] of information, both as...first class citizens. [T]he data models are general enough that they can be applied to essentially any kind of science data."*

Middleware project: *"...if you're building something that the users perceive to give them tools for doing the things they want to do, then they're likely to value it over the long haul."*

Framework project: *"I think one of the benefits [of standards development] is accelerated impact."*

3.4.6.2 Gap Filling

Framework project:*"...governments couldn't do everything to really utilize the earth science data that was coming from satellites... they recommended [an umbrella organization that would] include universities and commercial groups."*

Framework project: *"[T]he thing about the data citation principles...is because we had the publishers in our groups...we weren't just issuing declarations...but we were also able to...follow it up by implementation of recommendations and in some cases pilot projects."*

Database project: *[T]he best control of data quality is eyes on the data and revealing with thousands of people accessing data whereas they [the U.S. military] were dealing with very very limited numbers of...qualified people...*

Database project: *"...you send [staff] back out to work in some institution and they become a PI collaborator and they lead there"*

Framework project: *"...it's actually a community of people who have common problems around integration gaps and just by virtue of getting together in this community, they start to solve problems"*

Framework project: *"Did [the members] ever build a platform? No. Did we have the working groups? Yes."*

3.5 Strategic Development

3.5.1 Staying mission focused helps to navigate forks in the road

Database project:*"That was a compromise, if you will, that we made 20 years ago...We might be kicking ourselves just a little bit for making that decision, but we did and we're stuck with it."*

3.5.3 Lean into the unexpected

Database project: "*I don't know if they're going to be able to evolve the tools fast enough for the tools to continue to be, you know, valuable.*"

3.5.4 Staying relevant is a challenge for technologically centered projects

Database project: "*You can't build a system in 1996, and expect that it still works well in 2020. Right? So you have to make these updates that are huge efforts. They don't work in incremental ways obviously. That has been a big challenge to explain to the community and to NSF. That once in a while you need this kind of boost in funding to get something new…With incremental improvements, you run into the danger of becoming irrelevant or disconnected from the overall infrastructure developments.*"

Middleware project: "*You've got pressure to maintain the legacy software…there are always going to be people that would just like you to continue to keep doing what you're doing.*"

3.5.5 An abundance mindset creates competition but also benefits project mission

Middleware project: "*...they were quite happy to work with us, and we were quite happy to work with them on being essentially the distributor of this software and the offering of training services and how to use it.*"

Framework project: *"I always felt that we would lose part of our character, if we decided to deploy tools and infrastructures that competed with our membership, I didn't feel that the two things were compatible."*