



Research Software: A Key (Neglected) Component of the Digital Research Infrastructure Ecosystem

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Abstract

Technological advances have elevated the importance of digital research infrastructure across the research lifecycle. The growing complexity of the digital research infrastructure ecosystem gave rise to new standards, practices, and job roles requiring unique and specialised skill sets. Research software is a critical component of this ecosystem. Despite the proliferation of research software initiatives across all disciplines in South Africa, a decade-old global movement to study and advocate for research software and its developers has largely been overlooked locally, resulting in missed opportunities. By actively engaging in international research software efforts, South Africa can benefit significantly and contribute meaningfully.

Research software as part of digital research infrastructure

Digital research infrastructure (DRI) is “a necessary foundation for advancing commercialisable innovation, the practice of open science and social benefits from innovation.” (Abrahams and Burke, 2023)

The definition and scope of DRI are yet to be consolidated globally. Abrahams and Burke, 2023 identify the following layers: network and connectivity, computational, data, research and innovation communication, and governance. The glue that binds these layers and provides seamless access to DRI is software, often developed in research contexts, specifically for research purposes. Several countries have released national strategies and dedicated significant funding to developing DRI ecosystems that enable a functional research, technology, and innovation environment. Canada, the United Kingdom (UK), Australia and the Netherlands promote research software as a key component of DRI. Figure 1 provides an overview of the DRI ecosystem. It builds on the scientific software stack described by Hinsen, 2019, underscoring the importance of research software and its role in enabling research across all domains to address local, regional, and global societal needs.

Research software includes source code, algorithms, scripts, computational workflows, and ex-

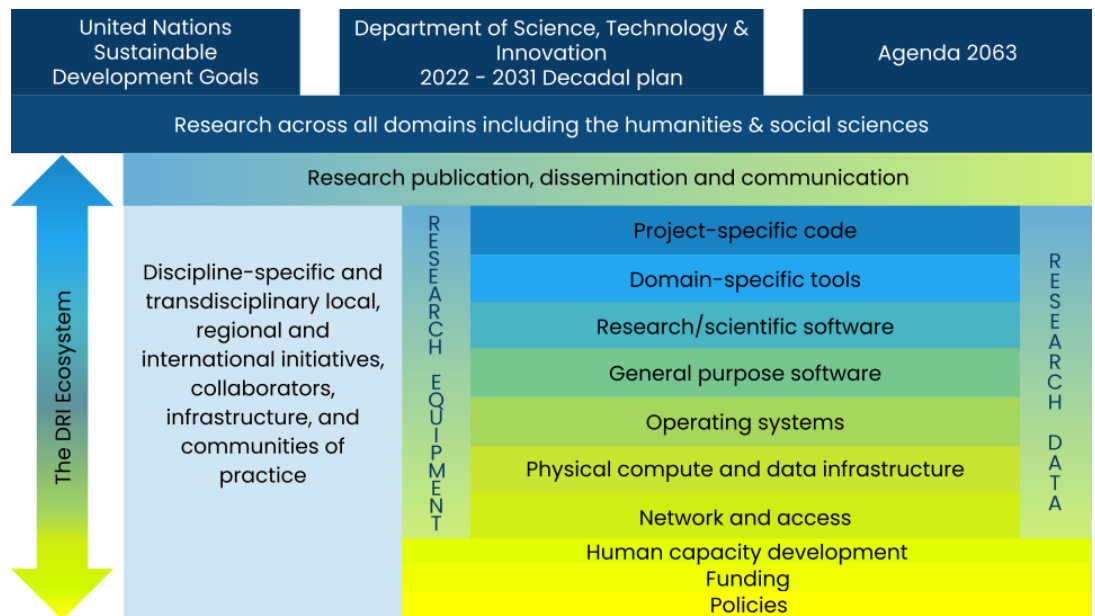


Figure 1. The Digital Research Infrastructure ecosystem highlighting software as an integral component.

ecutables created during the research process or for a research purpose (Gruenpeter et al., 2021). It is developed and used in all disciplines across the research lifecycle, underpins research as a tool, and should be recognised as an explicit research output. DRI users (researchers, postgraduate students, and the public and private sector) often do not consider each layer independently. They require seamless access to DRIs to generate, store, share, manipulate, analyse and visualise data, collaborate with peers, disseminate their research findings and engage with the existing body of knowledge. Figure 2 shows the pervasiveness of research software across the research lifecycle according to three high-level role categories into which research software can fall: modelling, simulation and data analytics software; proof-of-concept software; and research infrastructure software (Hasselbring et al., 2024).

Well-developed, sustainable research software provides ways to interface with and efficiently use DRIs. Efficient code can decrease the amount of storage used in analyses, the amount of bandwidth consumed when data sets are moved around, and the compute cycles utilised in data-crunching operations.

Global and local initiatives and communities

The UK Software Sustainability Institute (SSI), established in 2010, was the first organisation worldwide to focus exclusively on improving research software. The SSI has been instrumental in advancing research software practices, policy, funding, training, and supporting the development of the first national Research Software Engineering (RSE) society.

The UK's Society of Research Software Engineering was launched in 2014. Since then, Germany, Canada, Belgium, the Netherlands, and the United States (US) also created national research software societies. Multinational societies include Australia and New Zealand, the Nordic countries, and Asia. The Research Software and Systems Engineering Community of Africa, better known as RSSE Africa, was created in 2019 to build a network for skills sharing and discussions related to research software and systems in South Africa and beyond. The International Council of RSE Associations consists of representatives from the various RSE societies and provides space for them to connect and collaborate.

The Research Software Alliance (ReSA) was established in 2018 as a global organisation that engages specifically with funders and decision-makers regarding research software. The steering

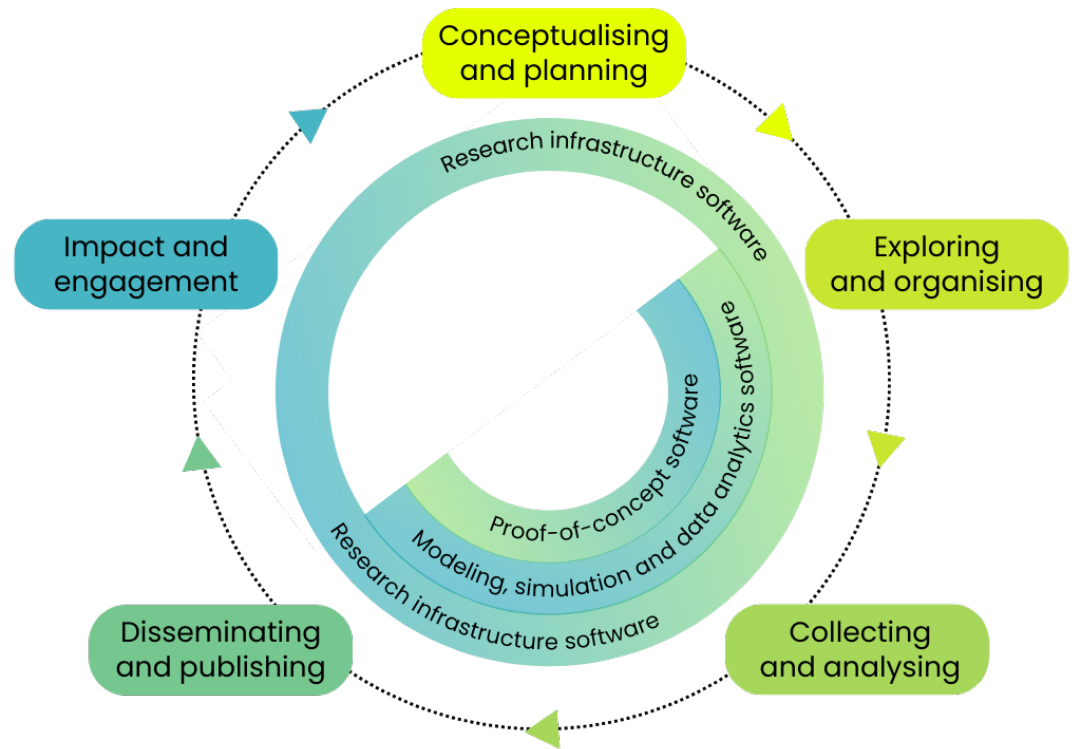


Figure 2. Research software plays a critical role across the research lifecycle.

committee consists of members representing the global research software landscape. ReSA follows a membership model, with current members including funders such as the Wellcome Trust, the Alfred P. Sloan Foundation, and the US National Institutes of Health, as well as research organisations such as the US National Aeronautics and Space Administration, the Netherlands eScience Center, and the Australian Research Data Commons.

Since research software is a developing field, much of the work around developing guidelines, standards, and best practices occurs through working groups. Two such international groups include:

- The FAIR for Research Software Working Group is a joint initiative between the Research Data Alliance’s Software Source Code Interest Group, ReSA and the Future of Research Communications and e-Scholarship community and developed the FAIR principles for research software (Barker et al., 2022) and
- ReSA and the Research Data Alliance jointly organise the Policies in Research Organisations for Research Software Working Group that brings together international stakeholders involved in institutional policy advocacy, development, and implementation.

The research software landscape is becoming increasingly complex, with numerous events to join, activities to participate in, and resources to adopt and contribute to. Figure 3 provides a slightly disentangled view of the ecosystem.

In South Africa, various national and sub-national actors provide services and infrastructure for different DRI layers. At a national level, the National Integrated Cyber Infrastructure System, managed by the Council for Scientific and Industrial Research, includes the Centre for High-Performance Computing, the Data Intensive Research Initiative for South Africa, and the South African National Research Network. Together with the Tertiary Education and Research Network, they aim to address needs around the network and connectivity, computational, and data layers.

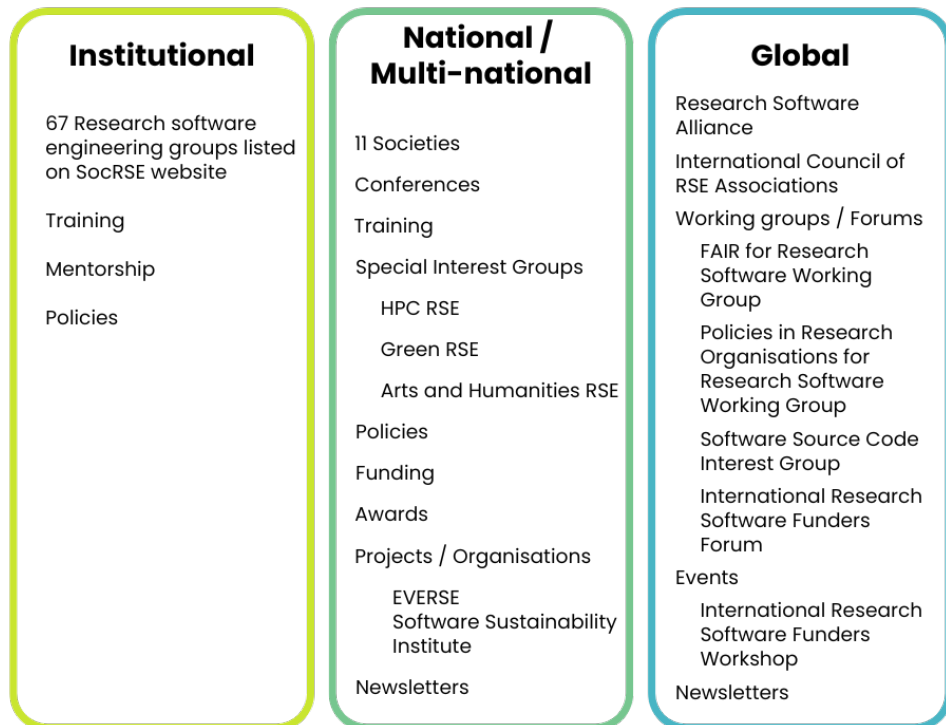


Figure 3. Examples of institutional, national, and global research software activities and initiatives offering opportunities for South Africa to collaborate with, participate in, learn from, and contribute to.

The government launched the South African Research Infrastructure Roadmap in 2016, which provides “a framework for planning, implementing, monitoring and evaluating the provision of research infrastructures necessary for a competitive and sustainable national system of innovation” (Department of Science and Technology, 2016). A working paper by researchers from the University of the Witwatersrand proposes establishing a national DRI platform to complement the work of the South African Research Infrastructure Roadmap (Abrahams and Burke, 2023).

Other examples of other large-scale national and regional initiatives contributing to the DRI and research software landscape include the following:

- National Institute for Theoretical and Computational Sciences (a multidisciplinary institute encompassing eight research themes);
- Data Science for Health Discovery and Innovation in Africa Initiative (focuses on data science skills and technologies related to health); and
- Square Kilometre Array project (astronomy and physics).

The DRI layers are also addressed to varying degrees at an institutional level. Universities and research organisations offer heterogeneous DRI-related services, infrastructure, and training portfolios. These can typically be accessed via institutional information technology departments, libraries, research or postgraduate offices, individual faculties, or sometimes only specific research groups.

In 2023, the first South African Research Software Indaba was held in Cape Town to provide a platform for discussing the global research software movement and locally relevant opportunities and challenges. Invited organisations included funders, policy-makers, and representatives from research programmes in astronomy, bioinformatics, health, humanities, computational sciences,

conservation, and the environment. All 20 participants indicated organisational involvement in various aspects of DRI, including software, via the event registration form (Table 1). A complete list of participating organisations is available in the event report (Van der Walt and Chalale, 2023). Similar to global trends over the past decade, research software underpins a significant amount of research findings across the breadth of research in South Africa. Further studies are necessary to gain a complete picture of roleplayers and their contributions.

Research Software Indaba registration form question: Does your organisation or initiative do any of the following?	Number of responses (n=20)
Research software or systems (data/compute) development and/or maintenance for in-house research	16
Training in research software or infrastructure development, maintenance, etc.	13
Employ research software or infrastructure developers	13
Research software or systems (data/compute) development and/or maintenance as a service to others	11
Provide access to specialised infrastructure on which research software runs (cloud/HPC)	11
Develop policies related to the research software ecosystem	9
Provide funding for research software projects, infrastructure, research, training, etc	8
Research software project management	8

Table 1. Responses from Research Software Indaba in Cape Town show that most participants' organisations are involved in DRI development, maintenance, training, funding, policy development, and more.

Policies, funding, and incentives

Internationally, funders and policy-makers increasingly prioritise research software in funding mechanisms and policies. ReSA maintains a public database of research software funding opportunities (Research Software Alliance, 2022). They also convene the Research Software Funders Forum, which provides a formal mechanism for sharing funding practices, understanding critical challenges within research software, expanding networks to identify collaboration opportunities, and exploring opportunities to achieve the long-term sustainability of research software. A key output of the forum's annual International Research Software Funders Workshop is the Amsterdam Declaration on Funding Research Software Sustainability (Eijnatten et al., 2022), which has 43 signatories, with the Science for Africa Foundation as the only African signatory. The declaration aims to "raise awareness of the role of funding practice in the sustainability of research software and to improve that practice".

ReSA hosts a growing list of institutional policies that offer a valuable starting point for organisations to develop their own (Research Software Alliance, 2023). Additionally, Open Science Europe's recommendations for developing research software policies provide helpful suggestions for research funding and research-performing organisations (Saenen, 2025).

Globally, numerous awards have been launched to promote research software and celebrate the people involved. These awards are sponsored by governments directly (for example, the French Ministry of Higher Education and Research) or through governmental agencies (for example, the Australian Research Data Commons and the US National Institute of Health). Paid fellowship programmes have been created to provide funding and access to mentorship, networks, and recognition for research software developers; for example, the SSI's RSE Fellowship Programme has supported more than 200 fellows.

In South Africa, several policies have been developed in the past decade to provide frameworks and guidelines for decision-making related to the local science, technology, and innovation ecosystem, including DRIs (see Table 2). These policies highlight the importance of networking, data, computing infrastructure, and research communication. They often also stress the importance of engaging with international DRI initiatives and communities of practice. However, none coherently addresses the need to develop the local research software or research systems landscape strategically.

Document	DRI Layers Included	Research Software Mentions
African Open Science Platform Strategy Document (Participants of African Open Science Platform Stakeholder Workshop et al., 2018)	<ul style="list-style-type: none"> • Network and connectivity • Computational • Data • Research and innovation communication • Governance 	Software infrastructure and a “Tools Network” that will manage localisation and awareness creation of software for research.
South African Research Infrastructure Roadmap (Department of Science and Technology, 2016)	<ul style="list-style-type: none"> • Network and connectivity • Computational • Data • Governance 	One of the 13 research infrastructures mentions it will develop research software.
National Research Foundation Framework to Advance the Societal and Knowledge Impact of Research (National Research Foundation, 2021)	<ul style="list-style-type: none"> • Research and innovation communication 	None.
Department of Science and Innovation’s Decadal Plan 2022 - 2032 (Department of Science and Innovation, 2022)	<ul style="list-style-type: none"> • Network and connectivity • Computational • Data • Research and innovation communication • Governance 	None.
National Big Data Strategy for Research, Development and Innovation (National Integrated Cyber Infrastructure System, 2022)	<ul style="list-style-type: none"> • Network and connectivity • Computational • Data • Research and innovation communication • Governance 	New software technologies for handling big data. Open science principles should be integrated with software development.
National Policy On Data And Cloud (Department of Communications and Digital Technologies, 2024)	<ul style="list-style-type: none"> • Network and connectivity • Computational • Data • Governance 	None.

Table 2. South African policies relevant to Digital Research Infrastructure.

South African research software endeavours are typically funded through larger research projects or international funding mechanisms. Applications to funders, such as the National Research Foundation, are vetted on academic track record, but research staff primarily focusing on creating, maintaining, and supporting research software typically do not grow their traditional academic track record through publications. In fact, the SSI's International RSE Survey found that more than 40% of respondents do not make it onto the co-author list in papers where the software they developed supported the research (Hettrick et al., 2022).

A closer look at the people behind research software

Research software development and maintenance pose unique challenges. Associated roles are becoming increasingly specialised and require 'scarce skills' linked to the Fourth Industrial Revolution. It requires knowledge of research practices and, in many cases, the scientific domain in which the software is utilised, as well as expertise in software development and usage best practices. Finding out who constitutes the people in research software is complex. The career paths to roles related to research software are not well defined, nor are job titles and descriptions. Roles related to research software may be based in academia across faculties, libraries, information technology, non-profit organisations such as national research and education network organisations, government, or industry.

An unpublished study conducted in 2014 by the SSI found that 400 out of 10,000 academic job advertisements related to research software development. These represented almost 200 different job titles, which could be generic, such as "postdoctoral research fellow" or "research associate," or specific, such as "senior RSE" or "high-performance computing engineer."

In 2012, a movement to study and advocate for individuals who develop research software was launched in the UK. The title "Research Software Engineer" was created to address the need to build an identity for the individuals behind research software and establish policies for career progression, training and impact measurement. Since then, the movement has expanded globally, and the term RSE has been adopted in Europe, the US, Australia, and New Zealand. It is important to note that a spectrum of roles exists in the research software space. On one end, we see researchers, often with limited formal training in coding, who develop scripts for data manipulation, analysis and visualisation. On the other end, we see professional software engineers with industry experience but potentially limited exposure to the research environment. Establishing the term "Research Software Engineer" is not a universal solution, nor does it address all challenges. However, South Africa can benefit from lessons learned through this approach to support researchers who spend significant time coding.

RSE groups employ professionals to support research software initiatives. Numerous RSE groups have been established at the institutional level, even though not all groups carry the title RSE to identify them. The UK Society of Research Software Engineering lists 67 (primarily UK-based) RSE groups. They vary considerably in size, focus, and location within research organisations. Some are established in domain-specific areas or embedded in research groups, while others are centrally located and provide services to the broader research community. Their funding mechanisms also differ significantly. Despite the relative lack of exposure to the term "RSE" in South Africa, numerous individuals and groups are involved in research software development, maintenance and related training. An African research software landscape study identified more than 60 South African communities, initiatives, and institutions engaged in various aspects of research software (Maphanga and Van der Walt, 2023). Not much is known about these groups' funding, skill sets, and scope of work.

The SSI runs an international research software survey every few years to gain insight into the demographics, job satisfaction, and practices of RSEs (Hettrick et al., 2022). In 2022, they reported more than 50% of RSE respondents globally had doctorate degrees. Only 23% of respondents had a computer science background, while the top disciplinary education was either in physics, as-

tronomy, biological sciences, mathematics, chemistry, geography and environmental sciences, or engineering. The fields in which respondents worked also included medicine, education, materials technology, agriculture and forestry, psychology, linguistics, and librarianship and information management, which points to some transferability of RSE skills across domains. RSEs are often part of multi-disciplinary teams that support and enable transdisciplinary research. The survey further indicated that more than half of the respondents were part of a dedicated research software group within their institution.

There is minimal data about research software-related roles in South Africa available. The 2017, 2018, and 2022 International Research Software Survey, respectively, recorded only 22, 23, and 2 responses from South Africa. Most respondents worked in physics or astronomy and had doctorate degrees with generic job titles like “research scientist”. Only a handful of respondents indicated being part of a dedicated research software group. The low number of responses does not reflect a lack of research software-related activity on the continent but perhaps instead points to a misalignment between the survey questions and terminology and the local contexts.

Anecdotally, many of the research software activities in South Africa rely on postgraduate students, postdoctoral research fellows, or personnel on short-term contracts with limited opportunities for academic career progression with variable expertise in making software or systems sustainable, accessible, interoperable, and reusable. Exceptions exist in flagship projects such as the Square Kilometre Array, the National Integrated Cyber Infrastructure System, and the South African Research Infrastructure Roadmap entities.

Not much is known about the career path to becoming an RSE. Since no straightforward degree programme or specific job title can be marketed to school leavers and undergraduate students, individuals accidentally stumble upon these roles based on their interests and through their networks Cosden, McHenry, and Katz, 2022. The research and technical skills of RSEs vary considerably. Often, an RSE may be an experienced researcher with limited software engineering experience or strong software engineering skills with less experience in any given research domain.

Due to the diverse entry points into RSE roles, few formal training opportunities exist, and a shared understanding of the minimal skill set required to be an efficient RSE is under development. In the study by Hannay et al., 2009, most respondents deemed self-study or learning from peers critical for developing the skills needed to build research software. More recently, Cosden, McHenry, and Katz, 2022 corroborated this finding through their research in the US.

Conclusion

South Africa performs world-class, impactful research across all disciplines. Research increasingly relies on access to DRI through research software. Supporting a vibrant research software environment ensures that research can benefit from and contribute to technological advances. A skilled research software workforce, from researchers who code to research software engineers to digital research infrastructure builders, is a key element of this enabling environment. The professionalisation of research software-related roles is a crucial aspect required to maximise the impact of investments in the DRI ecosystem to create innovative, interoperable, and sustainable solutions that advance research goals and ultimately benefit society at large. There is an urgent need to understand the existing and rich research software ecosystem in South Africa to inform policies and devise funding mechanisms and incentives for this fundamental research enabler.

Since research software also plays a significant role in achieving open science goals, open science mandates and funding can be harnessed towards promoting it. Importantly, open science efforts in Africa have primarily focused on open-access publications and open data. However, providing an increasing number of open-access publications and encouraging data sharing without equally supporting and developing the research software ecosystem cannot successfully enable open, reproducible science. To truly benefit from open science reforms, it will be critical to understand, acknowledge, and promote the role of other elements, such as research software and the

people responsible for its development and maintenance, through research, funding, incentive and policy-making.

Countries such as the UK, Australia, the Netherlands, and the US have made significant strides related to research software research, policy-making, funding, training, and collaboration. There are ample opportunities for South African research stakeholders to participate in, benefit from, and contribute to the global research software movement. Researchers who code can attend online training, community events, and conferences, often offered free of charge. Policy-makers and funders can engage with peers through working groups and forums to share recommendations and best practices.

The authors argue it is time to explicitly focus on policy, funding and incentives to promote sustainable research software - the glue that holds the DRI system together.

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