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Research software: A key (neglected) component of the digital research infrastructure ecosystem

Significance:

Technological advances have elevated the importance of digital research infrastructure across the research life cycle. The growing complexity of the digital research infrastructure ecosystem has given 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 been overlooked locally, resulting in missed opportunities. By actively engaging in international research software efforts, South Africa can benefit significantly and contribute meaningfully.

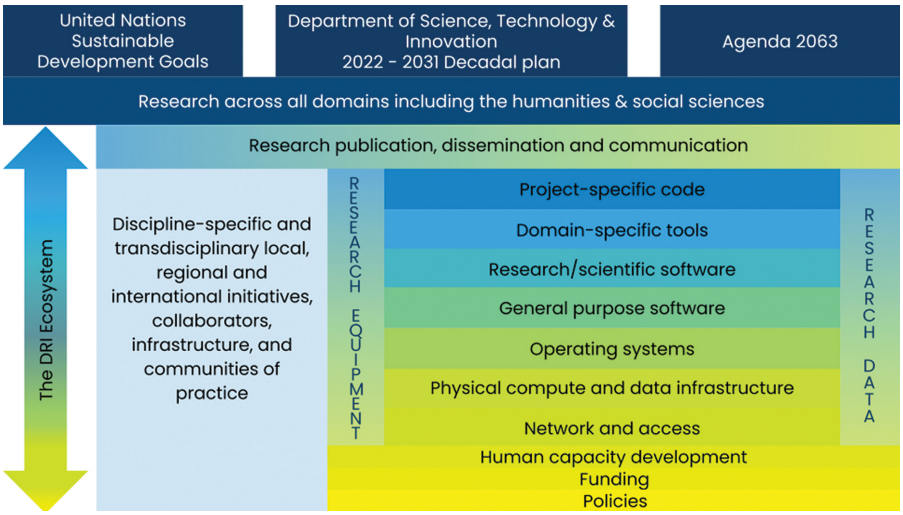
Research software as part of digital research infrastructure

Digital research infrastructure (DRI) is "a necessary foundation for advancing commercialisable innovation, the practice of open science and social benefits from innovation"[1].

Global stakeholders have yet to consolidate the definition and scope of DRI. Abrahams and Burke[1] identify the following five 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[2], 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 executables created during the research process or for a research purpose.[3] It is developed and used in all disciplines across the research life cycle, 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 life cycle according to three high-level role categories into which research software can fall: (1) modelling, simulation and data analytics software; (2) proof-of-concept software; or (3) research infrastructure software.[4]

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 moving data sets, and the compute cycles utilised in data-crunching operations.



Source: Elements of a typical software stack in scientific computing by Hinsen[2] were included in this figure and are reproduced under a Creative Commons CC BY 4.0 licence.

Figure 1: The digital research infrastructure (DRI) ecosystem highlighting software as an integral component.

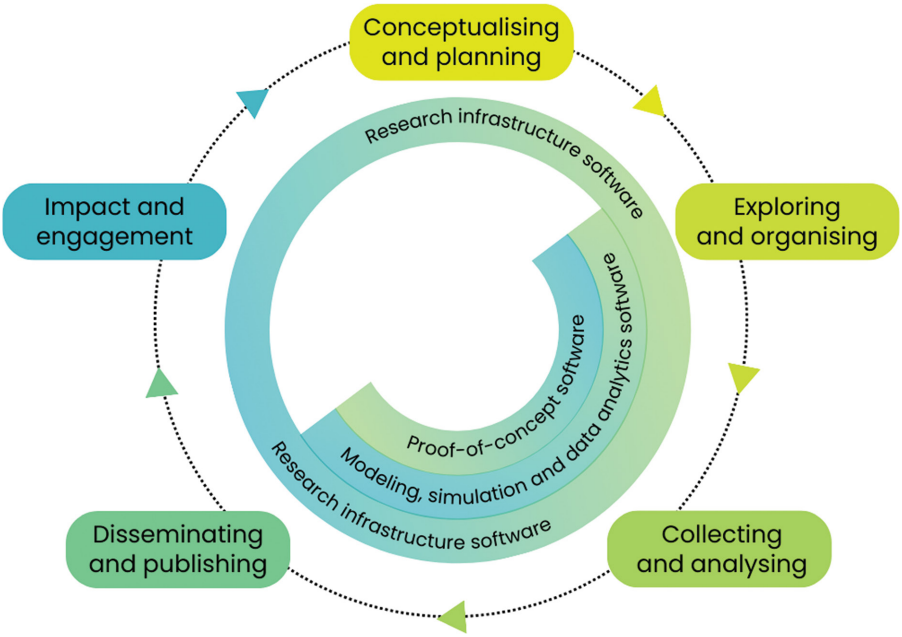


Figure 2: Research software plays a critical role across the research life cycle. The three high-level role categories into which research software can fall – (1) modelling, simulation and data analytics software; (2) proof-of-concept software; (3) and research infrastructure software, as identified by Hasselbring et al.[4] – were included in this figure.

Global and local initiatives and communities

The UK Software Sustainability Institute (SSI), established in 2010, was the first organisation worldwide to focus exclusively on research software. The SSI has been instrumental in advancing research software practices, policy, funding and 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 USA have 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), established in 2018, is a global organisation that engages specifically with funders and decision-makers regarding research software. The steering 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.

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

- FAIR for Research Software Working Group, which developed the FAIR principles for research software[5] and
- 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 in which to participate, and resources to adopt and contribute to. Figure 3 provides a slightly disentangled view of the ecosystem.

Various national and sub-national actors in South Africa provide services and infrastructure related to the 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. 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"[6]. A recent working paper proposes the establishment of a national DRI platform to complement the work of the South African Research Infrastructure Roadmap.[1] The National Institute for Theoretical and Computational Sciences, Data Science for Health Discovery and Innovation in Africa Initiative and Square Kilometre Array project are examples of large-scale national and regional initiatives contributing to the DRI and research software landscape. Universities and research organisations offer various DRI-related services, infrastructure, and training. Users can access institutional DRI resources via institutional information technology departments, libraries, research or postgraduate offices, individual faculties, or sometimes within 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, policymakers and representatives from research programmes in astronomy, bioinformatics, health, humanities, computational sciences, conservation and the environment.[7] Importantly, the event highlighted the pervasiveness of research software-related activities (including research software development and maintenance, as well as related training, funding and policymaking) across participating organisations. 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 role players and their contributions.

Policies, funding and incentives

Internationally, funders and policymakers increasingly prioritise research software in funding mechanisms and policies. ReSA maintains a public database of research software funding opportunities.[8] They also convene

SocRSE, Society of Research Software Engineering; HPC, high-performance computing; RSE, research software engineers/engineering; EVERSE, European Virtual Institute for Research Software Engineering; FAIR, findable, accessible, interoperable, reusable. Links to some of these resources and opportunities can be found on the RSSE Africa website at https://rsse.africa and in the reference list.

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

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[9], 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"[9].

ReSA hosts a growing list of institutional policies[10], offering a valuable starting point for organisations to develop their own. Additionally, Open Science Europe's recommendations for developing research software policies provide helpful suggestions for research-funding and research-performing organisations.[11]

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 Institutes of Health). Paid fellowship programmes 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 1). 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 landscape strategically.

South African research software endeavours are typically not funded through stand-alone grants, but as part of larger research projects. Funders vet submissions on the academic track record of the applicants, but staff primarily involved in research software development often 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 for which the software they developed supported the research.[12]

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 infrastructure 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. Research software roles can be found in academia (across faculties, libraries, information technology), non-profit organisations such as national research and education network organisations, government, and 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, UK researchers launched a movement to study and advocate for individuals who develop research software. 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. 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 amounts of time coding.

Table 1: South African policies relevant to digital research infrastructure (DRI)

Document	DRI layers included	Research software mentions
African Open Science Platform Strategy Document[13]	• 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[6]	• 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[14]	• Research and innovation communication	None
Department of Science and Innovation's Decadal Plan 2022–2032[15]	• Network and connectivity • Computational • Data • Research and innovation communication • Governance	None
National Big Data Strategy for Research, Development and Innovation[16]	• 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[17]	• Network and connectivity • Computational • Data • Governance	None

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. In South Africa, numerous individuals and groups contribute to research software development, maintenance and related training, even though they cannot be identified easily due to a lack of a common name such as 'Research Software Engineer'. An African research software landscape study identified more than 60 South African communities, initiatives and institutions engaged in various aspects of research software.[18] 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.[12] 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, astronomy, 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 multidisciplinary 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 available about research software-related roles in South Africa. The 2017, 2018 and 2022 International Research Software Surveys recorded only 22, 23 and 2 responses, respectively, 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.

The path to becoming an RSE is not well defined. Individuals often accidentally stumble upon these roles based on their interests and through their networks.[19] The research and technical skills of RSEs vary considerably. An RSE may be an experienced researcher with limited

software engineering experience or have strong software engineering skills with less experience in any 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.[20], most respondents deemed self-study or learning from peers critical for developing the skills needed to build research software. More recently, Cosden et al.[19] corroborated this finding through their research in the USA.

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 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. Understanding South Africa's existing research software ecosystem is urgently needed to inform policy, funding and incentives for this vital research enabler.

As research software also plays a significant role in achieving open science goals, open science mandates and funding can be harnessed towards promoting it. To date, open science efforts in Africa have primarily focused on open-access publications and open data. However, to truly benefit from open science reforms, it is essential to recognise and support research software and the people who develop and maintain it through research, funding, incentives and policies.

Countries such as the UK, Australia, the Netherlands and the USA have made significant strides related to research software research, policymaking, funding, training and collaboration. South African stakeholders have ample opportunities to participate in and contribute to this global movement. Researchers who code can access free online training and community events, while policymakers and funders can engage with international peers to share best practices.

We argue that 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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Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. All authors read and approved the final version.

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