LGC: CERN's geodetic network adjustment software goes open source

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SUMMARY

LGC ("Logiciel Général de Compensation") is a geodetic adjustment software package developed at CERN to compute position estimates and related statistics from surveying observations. Since the mid-1980s, it has been a key tool for precise geodetic computation in a wide range of applications - from simple levelling computations to advanced sensor-based position monitoring systems. LGC has evolved into a mature and reliable computation engine, continually maintained and improved by the CERN Geodetic Metrology Group.

In late 2025, the first open-source version of LGC was released. For the CERN Geodetic Metrology Group, this marks an important step towards a more sustainable and collaborative way of developing software. The goal is to move beyond internal use and share the tool with external users, from academia, industry and other research institutions. It also reflects the larger efforts of CERN, supported by the CERN Open Source Program Office (OSPO), to promote responsible open-source practices and ensure due diligence in software dissemination. The LGC project has directly benefited from the OSPO's guidance throughout this transition process.

The move to open source involved several organisational and technical challenges, including modernising legacy code, preparing open documentation, defining licensing and governance structures, and migrating the codebase to public repositories. In parallel, the development team conducted outreach activities by supporting external institutes and sharing knowledge within the accelerator surveying community. Although the community around LGC is currently modest, the growing interest from external parties highlights the clear potential for future collaborations, joint developments, and the exploration of diverse use cases for the tool.

In this paper, we report on the open-source transition of LGC and share the practical lessons learned during the process. In addition, we aim to encourage further exchange around sustainable, transparent, and open software practices within the geospatial community.

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1. INTRODUCTION

LGC ("Logiciel Général de Compensation", French for 'General Adjustment Software') has served as CERN's primary geodetic network adjustment software for nearly four decades. Developed initially in the mid-1980s to support the precision alignment of particle accelerators, LGC has evolved from a Fortran-based calculation tool into a comprehensive C++ platform supporting more than 20 observation models and sophisticated hierarchical coordinate system management. The software's capabilities have been refined through continuous operational deployment at CERN, where sub-millimetre alignment precision is routinely required for accelerator components.

While LGC's technical maturity and proven reliability in high-precision applications made it valuable to CERN's operations, its distribution model limited broader impact. The software was maintained as an internal tool, accessible only to CERN staff and selected collaborators through restricted licensing arrangements. This closed-source approach constrained knowledge sharing and prevented the wider geodetic community from benefiting from four decades of accumulated expertise in large-scale 3D network adjustment.

Interest from European accelerator laboratories — following discussions at the European Workshop on Accelerator Alignment (EUWAA) held at the European Synchrotron Radiation Facility (ESRF) in 2023 and at CERN in 2024 — highlighted a demand for accessible and transparent adjustment software as an alternative to commercial or in-house solutions (Mainaud Durand and Martin, 2024). These expressions of interest coincided with CERN's adoption of an Open Science Policy in October 2022 and the establishment of an Open Source Programme Office (OSPO) in 2023, providing an institutional framework for transitioning mature scientific software to open source.

In 2024, the software maintainers, with the support of their direct management, initiated the transition of LGC to an open-source model. This paper documents that transition process, examining the motivations driving the decision, the technical and organisational steps undertaken to prepare the software for public release, the early outcomes from initial community engagement, and the lessons learned. The paper targets the broader geodetic surveying community, recognising that the principles and challenges described apply beyond accelerator alignment to general surveying, industrial metrology, and high-precision geodetic applications.

2. LGC: A GEODETIC NETWORK ADJUSTMENT TOOL

2.1 Historical Development

LGC was originally developed in Fortran77 in the mid-1980s to process geospatial data from theodolites, distance meters, and horizontal wire offsets through least-squares adjustments in 3D coordinate systems (Iliffe, 1987). In the late 2000s, LGC underwent a complete rewrite in

C++ (Jones, 2010), introducing object-oriented programming and enhanced stochastic models. This modernisation included creation of SurveyLib, a C++ library providing mathematical routines, spatial objects, and geodetic transformations that have become the foundation for CERN's family of geodetic processing tools.

LGC Version 2, introduced in 2016 (Barbier et al., 2016), marked the latest significant evolution with the introduction of hierarchical reference frame capabilities. This innovation enables arbitrary hierarchies of coordinate systems, in which each frame is represented by a 7-parameter Helmert transformation (translations, rotations, scale), with parameters individually estimable or fixed. This capability supports complex geometric configurations including component fiducialisation, best-fit transformations, and sophisticated monitoring systems involving multiple coordinate systems.

LGC's development over its extended history has been made possible through the contributions of numerous individuals, ranging from entry-level surveyor trainees to experienced IT specialists. CERN surveyors have continuously tested the software, suggested new features, and pushed its capabilities through demanding project requirements. This collaborative evolution has shaped LGC into a comprehensive geodetic adjustment platform suitable for applications beyond its original accelerator alignment focus.

Today, LGC's core development team — referred to as maintainers in open-source terminology — represents approximately 1.5 full-time equivalents distributed across several profiles: mathematicians, IT specialists, and surveyors, all managing additional responsibilities within CERN's accelerator and experimental area surveying group. This small but diverse team covers the essential disciplines for geodetic software development: domain expertise, mathematical rigour, and software engineering. The maintainers are supported by the broader community of CERN surveyors who use LGC extensively in daily operations, providing continuous feedback and feature requests that drive ongoing development. This combination of focused development effort and extensive operational testing establishes LGC as a mature and reliable tool for 3D geodetic network adjustment.

2.2 Core Capabilities

LGC operates as a comprehensive 3D geodetic network adjustment toolkit employing rigorous least-squares estimation based on the Gauss-Markov model. The software processes observations with associated stochastic models to estimate coordinates and parameters while computing full variance-covariance matrices. Statistical validation through Chi-squared tests and detailed residual analysis enables outlier identification and network quality assessment. LGC supports constrained adjustments with fixed control points, semi-constrained adjustments with control points having associated precisions, and free network adjustments with dynamic constraints on the network centroid. The software provides various statistical indicators in result files and can be fine-tuned at every level, offering granular control.

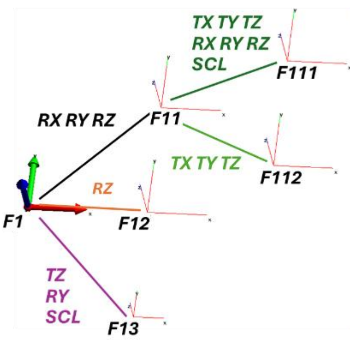
As of version 2.10.0 (November 2025), LGC supports more than 20 observation models from diverse instruments including total stations, laser trackers, hydrostatic levelling systems, wire positioning sensors, inclinometers, and digital levelling systems. Observation types include:

- **Polar observations:** Horizontal angles, zenith distances, spatial distances, and combined polar measurements (angle, zenith, distance)

- **Levelling observations:** Traditional vertical height differences and modern direct levelling with reference to a horizontal plane
- **Specialised observations:** Hydrostatic levelling sensors, wire positioning sensors, horizontal offsets to stretched wires, deviation to local vertical, and 3D Cartesian positions with associated precisions

The software allows for various point definitions, from completely free-floating parameters to fixed control points. Users can introduce multiple constraints on network parameters and select from diverse output formatting options, including the calculation of relative errors between selected points or relative transformations between coordinate frames.

LGC operates exclusively in 3D Cartesian XYZ systems. However, to accommodate the extensive geographic scope of CERN's accelerator complex, LGC manages three local geoid models (Ibarrola and Jones, 2016): a simple spherical model, the CERN Geoid 1985 (CG1985), and the CERN Geoid 2000 (CG2000). These geoid models are employed, for instance, when processing observations from total stations to establish the instrument's vertical vector in the CERN Coordinate System (CCS) expressed in XYZ coordinates. All three models, ranging from the simple spherical approximation to the more sophisticated CG2000, are specifically tailored to CERN's geographic area, enabling appropriate vertical reference determination within the CCS. The underlying SurveyLib library supports additional geodetic coordinate systems and their associated gravity reference surfaces — including multiple ITRF and ETRF realisations, Swiss and French national systems — not currently exposed in LGC as CERN's operations do not require them.




```
*FRAME  F1   0    0    0    0    0    0    1
 *FRAME  F11      1    1    0    0    0    0    1 RZ RY RX
  *FRAME  F111  1    0.5 0    0    0    0    1  TX TY TZ RX RY RZ SCL
  % [TX...RX...SCL] degrees of freedom of the frame w.r.t parent one
  % Observations, points and constraints can be defined in any frame
  *ENDFRAME %closing of Frame F111
  *FRAME  F112  1    -0.5     0    0    0    0    1  TY TX TZ
  *ENDFRAME %closing of Frame F112
 *ENDFRAME  %closing of Frame F11
 *FRAME  F12      1    0    0    0    0    0    1 RZ
 *ENDFRAME         %closing of Frame F12
 *FRAME  F13      1    -1   0    0    0    0    1   SCL RY TZ
 *ENDFRAME  %closing of Frame F13
*ENDFRAME %closing of Frame F1
```

Figure 1: Hierarchical frame structure with degrees of freedom, visualisation (left) and implementation in the LGC input format (right) based on keyword.

LGC offers the capability to construct coordinate systems as tree structures where each node represents a local Cartesian reference frame related to its parent through its 7-parameter transformation (Fig. 1). Optional pose constraints between reference frames within the hierarchical coordinate system model can also be expressed. Points and observations can be associated with any level of the hierarchy, and LGC automatically propagates transformations and uncertainties throughout the tree during adjustment. The flexibility to independently fix or estimate each transformation parameter enables sophisticated modelling of geometric relationships while maintaining rigorous uncertainty quantification.

2.3 Current State and Recent Developments

LGC operates as a command-line executable (Fig. 2). Users prepare an input file defining the network structure, observations, and computational parameters. LGC processes this file and produces results containing adjusted coordinates, estimated parameters, variance-covariance information, and statistical diagnostics. All output files are text-based and human-readable.
LGC version 2.10.0 is an actively maintained codebase. Recent developments focus on modernising interfaces and enhancing integration capabilities. Version 2.6.0 (June 2023) introduced JSON-based data serialisation, providing structured access to the full LGC dataset and results. This feature enabled development of modern analysis tools without modifying the LGC C++ codebase.

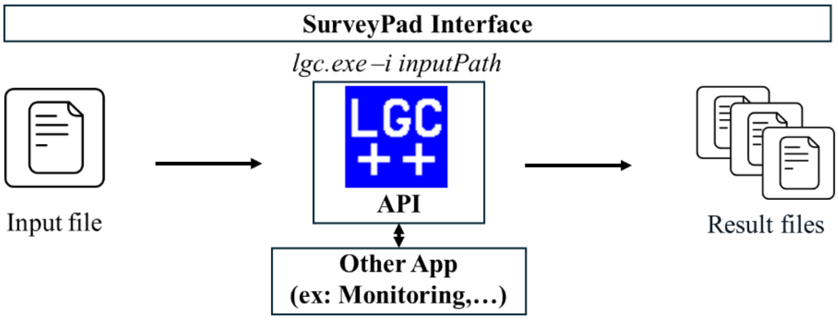


Figure 2: Basic ways to use LGC

The LGC Application Programming Interface (API), deployed in late 2023, provides methods to read input files, update measurements, launch analyses, and extract results. This development was driven by the Full Remote Alignment System (FRAS) project for the High-Luminosity Large Hadron Collider (HL-LHC) (Gutekunst et al., 2024), which demands position estimation at 1 Hz frequency.
SurveyPad (Lewandowski et al., 2022) provides a unified graphical user interface for multiple geodetic data-processing applications developed in-house (Fig. 3). The software integrates several data-processing tools: LGC for network adjustment, CHABA for best-fit transformations between point clouds via least-squares Helmert parameterisation, Rabot for smoothing accelerator element deviations, CSGEO for coordinate transformations between geodetic systems, and as of 2025, Shapes for fitting geometric primitives such as circles or planes onto point clouds. For LGC specifically, SurveyPad offers quality-of-life features including syntax highlighting of input files, linkage capabilities enabling navigation between output and input files, and graphical display of adjustment results. SurveyPad embeds a navigator capable of connecting to the CERN Survey Database via the GEODE interface and includes a built-in text editor. The interface supports scripting capabilities for pre- and post-processing workflows with Python as the preferred language. This unified environment significantly enhances accessibility compared to command-line-only operation, facilitating LGC adoption for users requiring integrated geodetic processing capabilities.
Comprehensive documentation at https://lgc2.docs.cern.ch/ has been publicly available since July 2025. Note that the LGC codebase, documentation, and JSON serialisation keys are in

English, while legacy text result files have historically been generated in French. SurveyPad generates HTML reports from LGC's JSON output, providing English-language results.
The main LGC software comprises over 30,000 lines of C++ code, while SurveyLib contains just under 50,000 lines. Rigorous quality assurance through approximately 150 test cases ensures consistency across updates. Additionally, a reception procedure comprising 150 to 200 LGC computations is analysed through a combination of manual verification and automated checks to ensure correct behaviour and prevent regression. Continuous integration/continuous deployment (CI/CD) pipelines automatically execute tests on Windows and Linux platforms, maintaining code quality as new features are integrated.

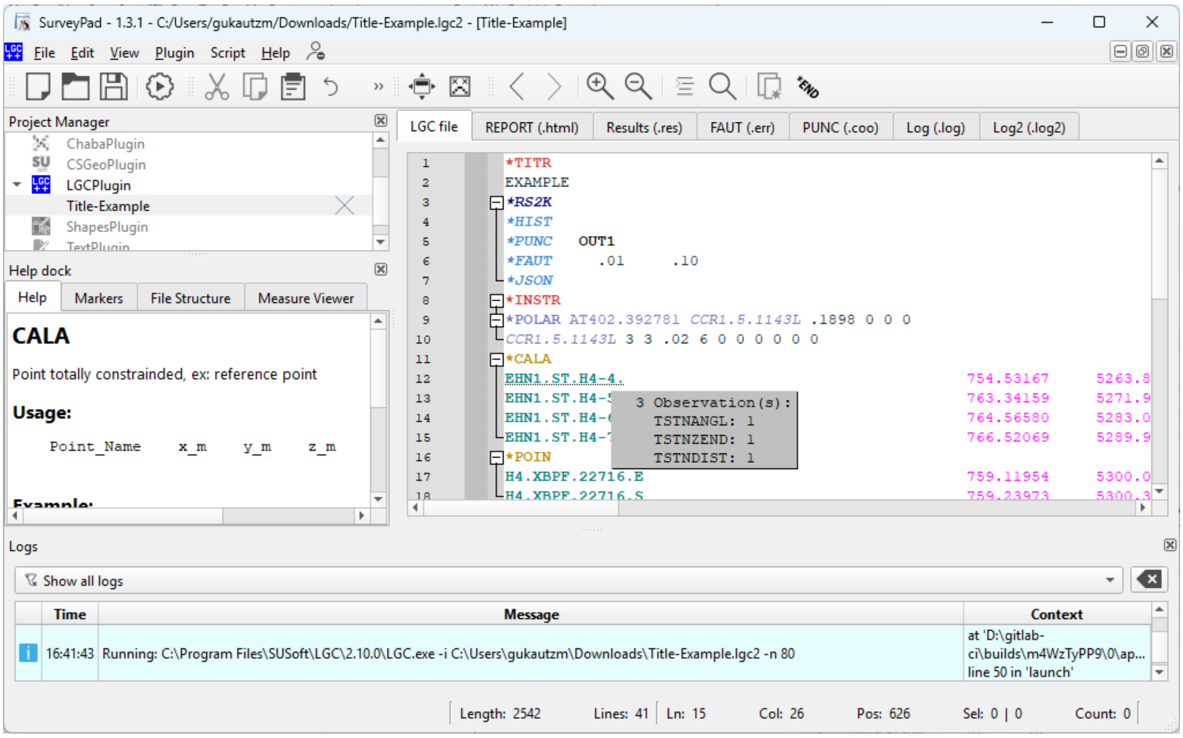


Figure 3: SurveyPad 1.3.1 interface for an LGC project, view on an example LGC input file.

3. THE CASE FOR OPEN SOURCE

3.1 External Drivers

The catalyst for open-sourcing LGC emerged from EUWAA meetings at ESRF (2023) and CERN (2024). Surveyor teams at accelerator and synchrotron facilities expressed strong interest in accessing LGC (Mainaud Durand and Martin, 2024).
Facilities currently rely on commercial software such as Spatial Analyzer, in-house developments, or projects with uncertain long-term sustainability. LGC, tested and refined over nearly four decades, remains under active development with strong institutional commitment at CERN. This prompted external facilities to encourage CERN to explore open-sourcing LGC as a community resource.

3.2 Strategic and Organisational Drivers

CERN's Open Science Policy, implemented in October 2022 (CERN, 2022), established a framework for open and collaborative research practices. It reaffirms CERN's commitment to promoting openness, collaboration, and the wide dissemination of knowledge for the benefit of science and society.

CERN's Open Source Programme Office, whose mandate was adopted in May 2023 (CERN, 2023), serves as the centre of competency for open-source operations. OSPO consults, advises, and trains the CERN community on best practices, tools, and licences. It manages a public catalogue of CERN's open-source software and hardware projects — OSPO serves as the key contact for accessing this catalogue. The OSPO provided the LGC maintainers with critical resources: expert guidance on licensing, contribution models, and community governance.

Beyond policy compliance, open-sourcing addressed fundamental questions of software sustainability and knowledge preservation. LGC's long development history requires mechanisms for knowledge transfer and community participation. An open-source model, with transparent development processes and public documentation, provides a pathway for long-term maintenance that closed-source models cannot replicate.

Crucially, LGC's maturity enabled this transition. With decades of development, rigorous validation, and extensive operational use, the software represented a stable, production-ready platform. CERN's status as sole copyright holder simplified licensing decisions.

3.3 Vision and Expected Benefits

Transitioning LGC to open source aims to foster a shared framework where geodetic surveyors across institutions can speak a common technical language and support one another rather than developing solutions in isolation. Building a user and contributor community is crucial for steering the software's evolution, adapting it to a wider array of applications, and improving its robustness through diverse operational experience. Open-sourcing also creates pathways for receiving enhancement suggestions, feature ideas, and bug reports from a broader user base. This enables the potential inclusion of contributors already familiar with the software, ensuring long-term development and maintaining integrity and continuity.

Contributions to LGC's ecosystem extend beyond core code development. Community contributors can provide pre- and post-processing scripts for SurveyPad, data format converters enabling interoperability with other software, documentation improvements, bug reports, and use-case examples. SurveyLib provides mathematical foundations potentially useful beyond LGC itself. This broader contribution model lowers barriers to participation, as valuable community input encompasses testing, feedback, and tool development.

From an educational perspective, open-sourcing LGC allows academic institutions to incorporate the tool into their curricula, providing students with hands-on experience in geodetic network adjustment and data analysis. This broader access could also engage universities and research groups in independent benchmarking and validation studies. To date, systematic cross-comparison with other adjustment solutions remains limited, with Durand et al. (2020) representing one of few published examples. Open collaboration has the potential to expand this body of work, strengthening confidence in geodetic adjustment methodologies across the community.

4. TRANSITION PROCESS AND IMPLEMENTATION

The open-source transition encompasses both LGC and its underlying library SurveyLib.

4.1 Planning and Preparation

The first step was engagement with CERN's OSPO. In April 2024, the LGC team submitted a formal request for guidance on licensing strategy, best practices for community development, and procedural requirements. The OSPO appointed a dedicated liaison, and regular meetings were organised to address questions, explore options, and align the project with CERN's open-source practices.

Code quality assessment revealed a favourable starting position. The legacy code was relatively clean with established testing frameworks.

4.2 Licensing and Contribution Model

For the source code, the GPL-3.0-or-later licence was selected, primarily because LGC depends on tree.hh, a C++ library distributed under GPL-3.0. The copyleft nature of this dependency effectively mandated GPL adoption for LGC. For documentation and non-code assets, the maintainers chose CC-BY-4.0.

The project adopted the REUSE Specification, ensuring machine-readable licensing throughout the codebase. This compliance facilitates automated licence verification, simplifies due diligence for organisations considering adoption, and provides legal clarity for contributors.

The contribution model uses the Developer Certificate of Origin (DCO) v1.1, a lightweight mechanism for contributors to certify submission rights via a `Signed-off-by` line in git commits. Contribution guidelines specify the workflow for community contributors: fork the repository, create a feature branch, commit changes with DCO sign-off, and submit a pull request. Licensing compliance is verified through REUSE checks. Code quality and adherence to project guidelines are ensured through automated pull-request checks and manual reviews by the LGC maintainers.

4.3 Repository and Infrastructure

The repository strategy uses a dual-platform approach. GitLab serves as the internal development platform, leveraging CERN's infrastructure and established CI/CD workflows. CERN's GitLab instance is accessible only to CERN account holders, addressing institutional security requirements. A public-facing repository on GitHub provides visibility to the broader open-source community. The organisation name "geodetic-metrology-tools" deliberately signals scope beyond CERN-specific applications. GitHub serves as the primary platform for community contributions, and development activities are expected to migrate progressively from GitLab to GitHub as the community grows.

GitLab runners on CERN infrastructure execute automated builds for Windows and Linux and generate installer packages. However, due to security policies restricting execution to CERN-vetted code, pull requests from forked repositories cannot trigger internal GitLab CI/CD pipelines prior to maintainer approval. As a result, contributors cannot access automated test results before their changes are accepted, which increases the review burden on maintainers and may slow external contributions. Migration to GitHub Actions is planned to address this constraint.

Since the public GitHub repository required thorough preparation, a phased rollout strategy was implemented. LGC and SurveyPad installer packages were published to a CERNBox (CERN's low-latency cloud data storage service) shared folder accessible via public link. SurveyPad binaries are included to ease immediate use, as command-line-only operation presents usability challenges for new users. This "soft launch" enabled early adopters to deploy LGC while the team completed preparation of the contribution infrastructure.

4.4 Documentation and Training

A substantial task involved comprehensive documentation overhaul. LGC's documentation had evolved organically over four decades, residing primarily in CERN's internal wiki system. A new public documentation site was created and deployed mid-2025 as the first publicly visible component of the open-source transition. The documentation effort extended beyond simple migration — content required restructuring for broader audiences with varying familiarity. The documentation strategy adopted phased priorities: user manual first, then mathematical model documentation, ultimately developer documentation. As of December 2025, the user manual phase has been substantially completed and is publicly accessible.

Developer documentation was consolidated directly within the project repositories on GitLab and GitHub, covering build requirements, dependency specifications, compilation instructions, and development environment setup. This provides immediate value to potential contributors. Further documentation may follow, but the current material should offer a solid starting point.

Training materials required substantial preparation. As LGC had been used primarily by specialists with deep domain and institutional knowledge, creating accessible introductory content demanded significant restructuring of how the software was explained. An extensive effort was undertaken to gather documentation previously spread across different systems and historical records into coherent, accessible materials. "LGC 101", organised over two afternoon sessions, was open to external institutes who joined via video-conference — demonstrating commitment to community engagement from the outset. The sessions were fully recorded, with presentation slides and video recordings publicly available via CERN's document management system. Earlier training on hierarchical frames was also made publicly available with recorded videos accessible. All release presentations from version 2.9.0 onwards are publicly available and document new features, bug fixes, and usage examples. These presentations will continue to be published with each release, providing accessible documentation of software evolution alongside formal technical documentation.

4.5 Community Outreach

Outreach preparation leveraged CERN's extensive network and former employees now working at other institutions. The paper and presentation at the International Workshop on Accelerator Alignment (IWAA) 2024 (Kautzmann et al., 2024) served dual purposes: communicating the open-sourcing strategy to gather early feedback while reaching the international accelerator alignment community. This FIG Congress 2026 paper continues these outreach efforts, extending visibility to the broader geodetic community.

A mailing list has been established for the community, providing news about LGC development, releases, and events. Interested parties are encouraged to contact the authors to be added to this distribution list.

5. OUTCOMES, LESSONS LEARNED, AND RECOMMENDATIONS

5.1 Initial Adoption and Validation

In November 2024, installer packages for both LGC and SurveyPad were published via CERNBox. The most significant early adoption came from ESRF in Grenoble, France. ESRF integrated LGC into network measurement workflows for accelerator alignment applications, providing genuine operational validation beyond CERN's environment. ESRF's engagement went further than simple use — the team submitted bug reports and developed their own custom interface to analyse LGC data, illustrating the value of open data formats and potential for community-driven innovation. Early adoption experiences provided valuable validation: community interest was genuine and substantial; bug reports demonstrated active engagement; custom development illustrated architectural extensibility; and documentation feedback revealed that investment in user manual development was necessary.

5.2 What Worked Well

Several strategic and tactical decisions proved particularly effective:

- **Progressive transparency:** Rather than waiting for a full simultaneous release, the team released components incrementally as they became ready while communicating openly about progress and blockers. The public documentation site was deployed before the code repository opened, providing immediate value. This approach built trust even when progress was slower than desired.
- **OSPO support:** The maintainers lacked expertise in open-source licensing and governance. The OSPO filled this gap by providing guidance while upping the team's competency in these areas. Their institutional authority also legitimised the transition within CERN's organisational structure.
- **AI-assisted workflows:** The team leveraged AI tools to accelerate specific aspects of the transition including framework implementation, website generation, and documentation assessment. These tools served as assistants rather than replacements for human expertise — all outputs were reviewed by domain experts.

5.3 Challenges Encountered

Several aspects proved more challenging than anticipated:

- **Documentation effort substantially exceeded initial estimates:** Migrating content, restructuring for external audiences, and filling gaps consumed far more resources than anticipated. Organically grown documentation accumulated over four decades inevitably drifted from best practices, requiring substantial housekeeping. Documentation for mature software necessitates considerable investment to reorganise, modernise structure, and ensure consistency — an aspect easily underestimated during planning.
- **Timing considerations introduced uncertainty:** CERN's OSPO was established in late 2023, and its processes were maturing when the LGC transition intensified. Some procedures underwent refinement during LGC's progression, introducing delays. The soft launch approach balanced preparation requirements with community demand for early access.

- **Licence choice constrained by dependencies:** LGC's reliance on tree.hh (GPL-3.0) effectively mandated GPL adoption due to copyleft requirements. Although GPL ensures improvements remain open, it may limit some industrial adoption where proprietary derivative works are desired. CERN's OSPO and organisational preferences lean toward permissive licences such as Apache-2.0, which encourage broader industry integration. Replacing the constrained dependency or coordinating with its maintainer could enable more permissive licensing. The maintainers welcome discussions with partners exploring integration options. LGC will remain open source under any future licensing model.
- **CI/CD access for community contributors:** Security policies prevent pull requests from forks from triggering internal CI/CD pipelines prior to maintainer approval, increasing maintainer burden. Migration to GitHub Actions is planned.
- **Language migration for result files:** Migration from French to English is complicated by SurveyPad's syntax highlighting and interface elements that parse result file text. LGC beta builds with full English translation have been publicly available since version 2.9.0, distributed alongside each stable release. SurveyPad's HTML reports from JSON output provide an additional English-language solution.
- **Balancing development cycles with operational requirements:** LGC maintains a six-month major release cadence. The November 2025 release had to be delivered as a stable platform six months before CERN's Long Shutdown 3 (LS3) — a multi-year accelerator maintenance period — begins in mid-2026. LS3 preparation involved approximately four years of heavily prioritised development on LGC and other surveying software, incorporating numerous feature requests from CERN's geodetic metrology group. The open-source transition coincided with this intensive preparation period, creating conflicting demands: delivering a production-ready platform for intensive operational use while simultaneously preparing the software for public release. While this timing added pressure on the maintainers, it also drove substantial improvements in documentation and training that ultimately benefited all users. In retrospect, whether this was the optimal timing for the transition remains an open question — the additional workload was substantial, though the outcomes were positive.

5.4 Critical Success Factors

Several factors enabled LGC's transition:

- **Single copyright holder:** CERN's ownership of all copyright eliminated negotiations about licence changes.
- **Pre-existing quality assurance practices:** Four decades of operational use refined algorithms and implementation. Crucially, development practices adopted since 2022 — such as systematic code review, disciplined issue tracking, a structured release strategy, and rigorous testing—were already in place, eliminating the need to establish these fundamentals during the transition. As a result, purely technical tasks such as REUSE compliance, repository configuration, and minor code refactoring proved straightforward. Contribution workflows were configured before opening to community contributors, avoiding subsequent remediation phases. The use of Git and proper version control procedures facilitated the move to public repositories.

- **Community interest as momentum:** Requests from EUWAA partner laboratories justified the allocation of resources, established planning-driven deadlines, and validated that the effort would deliver tangible benefits. ESRF's early adoption further reinforced the strategy and provided momentum. A key lesson learned: surf on the momentum by acting quickly and responding promptly to community demands. With ESRF specifically, the maintainers went further — organising comparative tests, video conferences to present LGC capabilities and address concerns. The message to potential adopters: don't hesitate to contact the maintainers — we strive to be responsive and welcoming. This personalised engagement sustained enthusiasm and demonstrated genuine commitment to community needs.
- **Management support:** Management backing for resource allocation and the institutional framework provided by the Open Science Policy were essential. Without management support, the transition would likely have stalled when operational demands intensified.

5.5 Recommendations for Others

Drawing on LGC's experience:

- **Do not underestimate documentation effort:** Even when legacy documentation appears easily transferable, assume two to three times initial estimates, particularly for restructuring, consistency checks, and adaptation to external audiences. Budget adequate resources.
- **Engage organisational support early:** Including legal expertise, an OSPO if available, and management approval with committed resource allocation.
- **Be transparent about limitations:** Communicate openly with potential adopters about blockers, approval processes, and realistic timelines. This builds trust and manages expectations. Consider partial releases — public documentation before code, interim distribution mechanisms — to demonstrate commitment and enable early feedback.
- **Communicate and reach out continuously:** Even during the transition phase, invest in outreach efforts. Document progress, present at conferences, and engage potential users early. Visibility builds momentum and attracts early adopters who provide valuable feedback.
- **Leverage AI tools:** Modern AI language models can substantially accelerate transition tasks including framework implementation, documentation assessment, and identifying content gaps. Human review remains essential for validation, but these tools proved highly effective when used as assistants for well-defined tasks.
- **Open-sourcing is not a one-time effort:** As community participation grows, governance structures will need to evolve. Licence choice implications should be reviewed based on community feedback. Balancing community requests with internal priorities remains an ongoing effort.

6. FUTURE OUTLOOK

Transitioning a large legacy project to open source demands substantial effort. While the technical migration itself is manageable, the surrounding tasks — documentation restructuring, training material development, community preparation, and ongoing engagement — require

sustained commitment. For projects with decades of accumulated complexity, this workload should not be underestimated.
Several technical tasks remain in progress. Complete English migration of legacy result files continues, with SurveyPad's HTML reports from JSON output providing an interim English-language solution. Integration of mathematical model documentation into the public website will provide comprehensive technical coverage, supporting transparency, independent verification, and academic use. Support for geodetic coordinate systems beyond those used at CERN and their associated gravity reference surfaces could further broaden reach.
Community infrastructure requires further development. A communication platform — potentially GitHub Discussions or a dedicated forum — will enable users to ask questions, share experiences and diverse use cases, and provide peer-to-peer support. Beyond technical exchanges, such a platform would foster the collaborative spirit at the heart of this transition: surveyors across institutions working together rather than in isolation, sharing solutions to common challenges. SurveyPad, currently distributed as compiled binaries, is planned for future open-source release, enabling community contributions to the interface itself and further lowering barriers to adoption.
LGC's technical roadmap will balance CERN operational requirements with community feature requests. Prioritisation will consider institutional needs — particularly during the LS3 shutdown period — alongside requests from the broader community. In short, the software must stay stable over time while adding features and refactoring, without significantly disrupting users' habits or workflows during this critical phase. Governance structures and a published development roadmap will be essential for coordinating contributions as participation grows.
While LGC originated in the context of accelerator alignment, the open-source transition positions it as a reusable resource for a wider range of applications, including general geodetic surveying, industrial metrology, and high-precision monitoring systems. The challenges and solutions described in this paper are therefore applicable to other organisations maintaining long-lived geodetic or surveying software, such as national mapping agencies, research institutions, and engineering consultancies.
The open-sourcing of LGC aligns with objectives embodied in the United Nations Sustainable Development Goals (SDG). By providing open access to advanced geodetic adjustment capabilities, LGC contributes to SDG 9 (Industry, Innovation and Infrastructure) through democratised access to high-precision analytical tools, SDG 4 (Quality Education) by supporting training and academic use, and SDG 17 (Partnerships for the Goals) by enabling international collaboration around shared, transparent software infrastructure. This approach aligns with FIG's broader principles of openness and collaboration in geospatial practice, with open-source software enabling transparent and reproducible use of geospatial data.

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Francis Klumb holds a PhD in surveying engineering and is a section leader within the Geodetic Metrology Group, where the development and long-term maintenance of LGC are coordinated.
Rishabh Singh is an IT engineer who joined the LGC team in 2024, contributing to the maintenance and modernisation of its codebase and associated tools, including SurveyPad.
Philip Elson is a software engineer with extensive open source development experience, serves as the OSPO representative for software in the Beams department, and is the liaison for the LGC project.

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