

Impact stories

Project name: Photonics and Materials Research Infrastructure: Printable Luminescent Materials, PRILUMAT



**Funded by
the European Union**

NextGenerationEU



Research Council of Finland

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Accelerating Sustainable Photonics: Inkjet-based 3D Printing and Optical Profilometry for Next-Generation Optical Components

Executive summary

This impact story describes how RRF-funded acquisitions—an inkjet-based 3D printer for optical components and a state-of-the-art optical profilometer—have strengthened the university's research infrastructure and enabled new capabilities in the rapid, resource-efficient fabrication of photonic components (e.g. microlenses, light guides and gradient-index optics). The optical profilometer was procured and commissioned in 2024 and the 3D printer in 2025. Together, they create an end-to-end pipeline from digital design through additive manufacturing to high-precision surface metrology.

The printer's open software stack and multi-material capability (including the ability to combine different refractive indices and integrate absorptive or luminescent media) expands the design space beyond that of conventional fabrication and shortens prototyping cycles, benefiting researchers, students, and industry collaborators. Early technical outcomes include the successful printing of apertures inside optical components, as well as promising preliminary results in gradient index (GRIN) optics. The infrastructure is actively used by a diverse range of users at different career stages and from different countries, with high utilisation across internal research, national and international academic collaborations, and company-funded R&D projects and services.

Although integrating luminescent materials into UV-curable systems has proven challenging due to potential degradation of emission properties upon mixing, the team has defined a clear path to address material compatibility and stability. The investments will advance sustainable growth by improving research productivity and skills, supporting energy-efficient photonic solutions and opening infrastructure for shared academic-industry use. This will contribute to Finland's Sustainable Growth Programme and the EU's green and digital transitions.

1. Impact objectives

The overarching objective was to promote sustainable growth by reinforcing high-level research infrastructure that catalyses:

- Sustainable society: producing new research knowledge and methods to accelerate optical component R&D and enable energy-saving photonic solutions.
- Sustainable well-being: enabling resource-efficient, environmentally friendly solutions (e.g., efficient lighting and data-centre optics) and developing skills through hands-on training.
- The sustainability of public finances: enhancing the open, shared use of infrastructure (including services for companies), improving research efficiency, and leveraging RRF investment for wider socio-economic benefits.

A complementary objective was to strengthen the university's role as a national and European research environment that supports academic research, education, and industry-stakeholder collaboration.

2. Actions

Procurement and commissioning. The optical profilometer was acquired and installed in 2024 to replace a legacy unit that was beyond repair. Meanwhile, the inkjet-based 3D printer for optics was acquired and commissioned in 2025. Together, these two pieces of equipment establish a digital-physical workflow for design, fabrication, and metrology.

Technology description and capability build-up. The 3D printer fabricates optical structures layer by layer by jetting picolitre-scale droplets of photopolymers onto targeted regions, followed by UV curing to create transparent, dimensionally accurate structures. Multi-material printing enables the combination of materials with different refractive indices within a single monolithic component, such as GRIN optics in which the refractive index changes smoothly. It also allows for the integration of absorptive media, for example for the formation of apertures, and the selective addition of luminescent materials. Furthermore, support materials can be used to create fully freeform 3D geometries. The optical profilometer supports the metrology of surface form and roughness of fabricated components, thereby closing the loop for process optimisation and quality assurance. The printing hardware/software stack is open on the control side, facilitating fine-grained control and method development.

User base, training and openness. The infrastructure caters for all career stages, including professors, postdoctoral researchers, doctoral researchers and master's students, and welcomes people of all genders and nationalities. It is used for in-house research, national and international collaborations, company-driven R&D, fee-based services and



degree/doctoral education, all under the guidance of experienced researchers.

3. Successes and challenges

Successes

- High utilisation for national and international research and industry collaboration services.
- Open, controllable software implementation enables efficient process management and method innovation.
- Multi-material capabilities are operational, including combinations of refractive indices for GRIN optics, absorptive layers for integrated apertures, support materials for complex freeforms, and the targeted introduction of luminescent media. Apertures have been successfully printed inside optical components such as beam shapers, and the preliminary results for GRIN are promising.
- Adoption of a globally unique 3D printing technology for research purposes, creating a distinctive competitive edge for the infrastructure.

Challenges

- Luminescent-UV-curable material compatibility: while incorporating luminescent materials into UV-curable resins has led to diminished emission properties, ongoing optimisation of resin formulations and curing protocols is aimed at restoring and improving performance.

4. Impact mechanisms

1) *Research impact*: by enabling the rapid digital prototyping of complex optical forms, such as freeform surfaces, GRIN profiles and microfluidic channels, the infrastructure shortens iteration cycles and paves the way for more compact and efficient optical systems. Profilometry ensures metrology-driven optimisation, resulting in higher-quality outputs.

2) *Skills and education*: Students and early-career researchers gain hands-on experience with cutting-edge photonics manufacturing and metrology. This strengthens human capital for Finland's green and digital transition, while also improving their employability in high-tech sec-

tors.

3) *Societal and industrial relevance*: Advancing energy-efficient photonics (e.g. improving light management in lighting or data centre optics) contributes to greater resource efficiency and reduced emissions further down the line. Companies can access the platform via fee-based usage of equipment or service activities, which supports the development of market-relevant prototypes and products.

4) *Systemic value*: The platform integrates infrastructure, expertise, training, open practices and industrial use cases to create a self-reinforcing ecosystem in which results and methods propagate across projects and sectors.

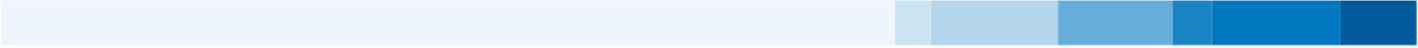
5. Medium- and long-term impact and systemic effects

Medium term (next 2-4 years): Improved energy and resource efficiency through: improved optical components for, e.g., lighting and solar/photonic energy management; fewer parts per system via freeform/GRIN designs; shorter prototyping without costly moulds or grinding and polishing, enabling faster experimentation and validation. Industrial uptake: company pilots and fee-based services convert research know-how into TRL advancement, reducing the risk of innovative optical solutions for SMEs and larger firms.

Long term (4-10+ years): There will be cost and supply-chain benefits in low-volume, customised optics, where additive methods can outperform conventional fabrication in terms of time to market and total cost of ownership. Functional integration involves co-printing optical, mechanical and potentially functional (e.g. luminescent) features to reduce assembly steps, mass and waste, enabling the production of lighter, more compact modules. Sustainability gains: material-efficient additive processes and the potential for distributed, on-demand production reduce logistics impacts. *Systemic impact*: the ecosystem—comprising methods, datasets, trained personnel, and industry connections—facilitates the broader adoption of advanced photonics manufacturing across academia and industry.

6. EU-level impact

The research directions and demonstrators support the ambitions of the EU Green Deal by enabling energy-efficient optical technologies and promoting resource-efficient manufacturing approaches. The infrastructure strengthens European collaboration and mobility by providing shared advanced capabilities that attract joint projects and



researcher exchanges. It also aligns with the priorities of Finland's Recovery and Resilience Plan to accelerate the green and digital transitions through research, innovation and skills.

7. Monitoring and evaluation indicators

The infrastructure may continue to monitor and track the following:

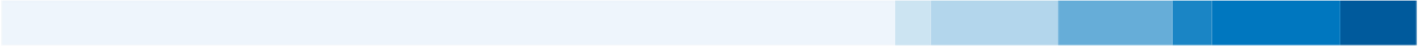
- The number of measured/printed samples and active users (by unit/organisation and career stage).
- Peer-reviewed publications, conference papers, theses, and citations attributable to the infrastructure.
- Education outcomes: completed MSc (Tech) and PhD (Tech) theses, and user feedback on skill development.
- Collaboration and service activity: the number and value of company projects, external academic collaborations, and cross-border initiatives.
- Evidence of downstream societal or environmental benefits (e.g., efficiency gains in applications), together with qualitative case narratives from partners.

Early results and illustrative cases

- Printed apertures that are integrated directly into optical components demonstrate how absorptive materials can be co-printed to reduce the number of parts and the assembly process, with immediate implications for miniaturisation and controlling stray light.
- Preliminary GRIN printing indicates the feasibility of creating tailored refractive-index profiles, which could improve light control and reduce the number of elements in imaging or illumination systems, paving the way for more compact and efficient devices.

Lessons learned

- Open control enables innovation. The open software/control implementation is essential for process learning and reproducibility, and it accelerates progress towards advanced toolpaths, multi-material sequencing and in-situ parameter tuning.
- Materials science is pivotal. The challenge of achieving compatibility between luminescent and UV-curable materials highlights the



need for iterative formulation, photoinitiator selection and cure-schedule engineering to preserve optical performance.

- People and diversity matter. A diverse user community comprising different genders, nationalities and career stages strengthens method development and broadens the scope of potential applications.

Next steps (2026 and beyond)

- 1) Resolve luminescent integration by screening alternative host resins, stabilisers, and UV protocols to maintain emission properties and validate these using optical characterisation.
- 2) Mature GRIN optics by quantifying refractive-index gradients and wavefront performance. Then co-design freeform-GRIN elements to reduce the number of parts in demonstrator modules (e.g. coupling and objective optics).
- 3) Method documentation and training: publish scientific results and educate researchers in photonic technology.
- 4) Industry pilots: target energy-efficiency use-cases (e.g. lighting and other photonics) to demonstrate environmental and cost benefits.

Communication and use of results

The team will continue to publish in peer-reviewed journals, incorporate findings in theses and share methods with partners. The service model of the infrastructure for companies and collaborative projects ensures that know-how flows into innovation pipelines, where societal and economic impacts are realised.

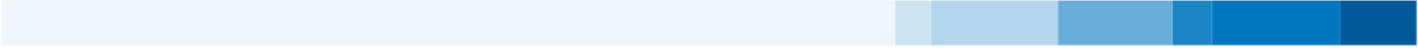
X-ray diffractometer - irreplaceable tool in structural analysis of new Luminescent materials - Research Group Perspective

Thanks to RRF funding, our research group was able to invest in a single-crystal X-ray diffractometer, strengthening our ability to conduct high-level, sustainable research and respond to major societal challenges in energy efficiency, materials science and bioeconomy. Access to state-of-the-art structural characterisation is essential for us to generate new knowledge that supports the development of resource-efficient and environmentally responsible technologies. At the same time, consolidating several ageing, fragmented instruments into a single, modern platform has enabled us to utilise public research funding more efficiently, while also building a robust infrastructure that will provide value for 15–20 years. This investment has also strengthened our role as a national and European hub for crystallographic research, serving academic partners, industry and the wider scientific community.

We acquired and commissioned the Rigaku XtaLAB Synergy S single-crystal X-ray diffractometer in 2024. Diffraction analysis is a central method in chemical and materials research because it is the only technique that can determine three-dimensional molecular structures with atomic-level precision and high accuracy, with virtually no limitations on the complexity of the species being investigated, provided suitable crystals of the sample can be obtained. This crucial information underpins our understanding of the relationship between structure and properties, and guides the rational design of new functional molecules, materials, catalysts, drugs and much more. This new instrument has replaced four outdated diffractometers, significantly improving the reliability, efficiency and sustainability of our experimental workflows.

The diffractometer has become an integral part of our daily research activities. We use it extensively within our research group and across the university, regularly analysing crystalline samples from other European universities as part of collaborative projects. We also provide crystal structure determination services for materials research and actively use the facility for teaching and supervision. Master's and doctoral students receive hands-on training on advanced research infrastructure under the guidance of experienced tutors. We consider this training to be a core component of developing future scientific expertise. We disseminate the results of our work through peer-reviewed publications, and we deposit all newly solved crystal structures in the Cambridge-Crystallographic Data Centre to ensure that our data is openly available to the global research community.

Since commissioning the instrument, we have observed improvements in the quality and efficiency of our research. The high-sensitivity

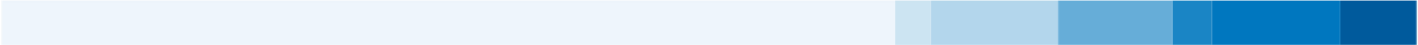


detector enables us to collect high-quality diffraction data many times faster than before, allowing us to undertake more ambitious research projects and complete iteration cycles more quickly. The instrument is powerful enough to make preliminary structural determinations of large bio-organic molecules, such as peptides and proteins. We can then investigate these further at large-scale facilities, such as the European Synchrotron Radiation Facility, when needed. The diffractometer is used by researchers at all career stages, from professors to MSc students, in an inclusive, internationally diverse research environment that reflects balanced gender representation and strong international collaboration. The data generated has already contributed to high-quality scientific publications and open-access structural databases. However, we are aware of the method's inherent limitations: not all compounds of interest crystallise, or do so with sufficient quality, which continues to pose a scientific challenge.

The impact of the diffractometer on our work extends beyond individual experiments. Precise crystal structure determination enables us to uncover intrinsic properties, propose synthetic routes and predict the physical and chemical behaviour of objects ranging from small molecules to enzymes, which would otherwise remain inaccessible. A historical example that illustrates the practical use and importance of crystallography is the determination of the structure of penicillin in the 1940s, which boosted the development of antibiotic treatments by creating synthetic modifications of the naturally produced parent compound. Through hands-on training, we strengthen the methodological competence of students and early-career researchers, preparing them for careers in academia and industry. Our research outcomes support broader societal goals by contributing to advances in energy efficiency, renewable materials and transitioning away from fossil-based resources.

In the medium term, the infrastructure will enable us to focus primarily (although not exclusively) on molecular chromophores, which are efficient luminescent materials used in lighting and solar concentrators, smart and stimuli-responsive materials, and photovoltaic devices such as solar cells. Improvements in luminescent materials directly contribute to energy savings, given that lighting accounts for a significant proportion of global electricity consumption. We also use the instrument to advance structural studies of enzymes, supporting the optimisation of biocatalytic processes.

In the longer term, our structural characterisation of key enzymes, including aldopentionate dehydratases, will support the development of non-phosphorylative oxidative pathways for converting lignocellulosic biomass into fuels and high-value chemicals. Through this work, we aim to contribute to replacing fossil resources with renewable, environmentally friendly feedstocks, thereby reducing environmental pollution and pressure on natural resources. We view the overall impact as systemic,



encompassing research infrastructure, education, open data practices and innovation pathways relevant to industry.

At the European level, we closely align our research with the objectives of the European Green Deal, particularly regarding energy efficiency, renewable resources and emission reduction. We actively support the European Research Area by openly depositing crystal structures in the Cambridge Crystallographic Data Centre, thereby promoting transparency, data reuse, and cross-border collaboration. We also promote European research cooperation by sharing sample analysis and exchanging data with our partners.

We continuously monitor and evaluate the impact of the infrastructure by tracking the number of measured samples and active users, scientific publications and citation metrics, the number of new crystal structures deposited in the CCDC, training outcomes for students and early-career researchers, and the scope and continuity of national and international collaborations. This systematic approach enables us to assess the infrastructure's long-term impact and further develop its scientific and societal value.