Call: HORIZON-EIC-2022-PATHFINDEROPEN-01

(EIC Pathfinder Open 2022)

Topic: HORIZON-EIC-2022-PATHFINDEROPEN-01-01

Type of Action: HORIZON-EIC

Proposal number: 101099125

Proposal acronym: 3D-BRICKS

Type of Model Grant Agreement: HORIZON Action Grant Budget-Based

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1 - General information

Fields marked * are mandatory to fill.

Topic	HORIZON-EIC-2022-PATHFINDEROPEN-01-01	Type of Action	HORIZON-EIC
Call	HORIZON-EIC-2022-PATHFINDEROPEN-01	Type of Model Grant Agreement	HORIZON-AG

Acronym 3D-BRICKS

Proposal title 3D Biofabricated high-perfoRmance dna-carbon nanotube dIgital electroniCKS

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Duration in months 36

Free keywords *nanoelectronics; DNA nanotechnology; carbon nanotubes;*

Please select between 3 and 6 descriptors that best characterise the subject of your proposal, in descending order of relevance.

Descriptor 1	**Discipline:** Physical sciences **Subdiscipline:** Nanophysics: nanoelectronics, nanophotonics, nanomagnetism, nanoelectromechanics, etc. **Descriptor:** Nanoelectronics
Descriptor 2	**Discipline:** Biotechnology **Subdiscipline:** Industrial biotechnology **Descriptor:** Synthetic biology, chemical biology and new bio-engineering concepts
Descriptor 3	**Discipline:** Electrical and electronic engineering **Subdiscipline:** Electrical and electronic engineering **Descriptor:** Electrical and electronic engineering: semiconductors, components, systems

Administrative forms

Proposal ID	**101099125**
Acronym	**3D-BRICKS**

Abstract *

Silicon-based CMOS technology is approaching its performance limits, but the demand for more powerful computers — driven by rapid advances in applications such as the Internet of Things, big data and artificial intelligence (AI) — remains. The discovery of various nanomaterials provides new opportunities to further develop information processing technology. Carbon nanotubes (CNTs) have, in particular, demonstrated excellent properties as a channel material in transistors. Computers based on CNT field-effect transistors (FETs) have been theoretically predicted to provide a power-performance improvement of ten times over computers based on Si-CMOS technology. However, the fabrication of high-performance CNT-nanoelectronics, and the realization of the full potential of CNTs, is highly challenging. A technological revolution would be a reliable approach to fabricate a new family of CNT-based devices that could enable aligned arrangement of the nanotubes avoiding the critical steps related to nanolithography. In particular, biofabrication using DNA-templated CNT arrays FETs has been demonstrated to further scale the alignment of CNTs within the FETs well beyond standard lithographic feasibility. 3D-BRICKS will raise this concept of integrated self-assembly CNT-nanocircuits to a completely new level by moving towards the third dimension. Indeed, the versatility of DNA nanotechnology will be the root for conceiving 3-dimensional (3D) CNT-FETs and CNT-nonvolatile memories. DNA nanotechnology will also enable to complement the CNT deposition with metallic connections, hence realizing a working circuit. This will reduce the foot-print of the final device while enhancing its efficiency, hence providing a breakthrough solution to realize the next-generation nanoelectronics. Our approach will enable the production of scalable biotemplated electronics that can be extended to multiple applications such as metamaterials, sensors, optoelectronics, and others.

Remaining characters 24

Has this proposal (or a very similar one) been submitted in the past 2 years in response to a call for proposals under any EU programme, including the current call? (•) Yes ( ) No

Please give the proposal reference or contract number.
101047328

Administrative forms

Proposal ID	**101099125**
Acronym	**3D-BRICKS**

Declarations

Field(s) marked * are mandatory to fill.

1) We declare to have the explicit consent of all applicants on their participation and on the content of this proposal. *	☒
2) We confirm that the information contained in this proposal is correct and complete and that none of the project activities have started before the proposal was submitted (unless explicitly authorised in the call conditions).	☒
3) We declare: - to be fully compliant with the eligibility criteria set out in the call - not to be subject to any exclusion grounds under the EU Financial Regulation 2018/1046 - to have the financial and operational capacity to carry out the proposed project.	☒
4) We acknowledge that all communication will be made through the Funding & Tenders Portal electronic exchange system and that access and use of this system is subject to the Funding & Tenders Portal Terms and Conditions.	☒
5) We have read, understood and accepted the Funding & Tenders Portal Terms & Conditions and Privacy Statement that set out the conditions of use of the Portal and the scope, purposes, retention periods, etc. for the processing of personal data of all data subjects whose data we communicate for the purpose of the application, evaluation, award and subsequent management of our grant, prizes and contracts (including financial transactions and audits).	☒
6) We declare that the proposal complies with ethical principles (including the highest standards of research integrity as set out in the ALLEA European Code of Conduct for Research Integrity, as well as applicable international and national law, including the Charter of Fundamental Rights of the European Union and the European Convention on Human Rights and its Supplementary Protocols. Appropriate procedures, policies and structures are in place to foster responsible research practices, to prevent questionable research practices and research misconduct, and to handle allegations of breaches of the principles and standards in the Code of Conduct.	☒
7) We declare that the proposal has an exclusive focus on civil applications (activities intended to be used in military application or aiming to serve military purposes cannot be funded). If the project involves dual-use items in the sense of Regulation 2021/821, or other items for which authorisation is required, we confirm that we will comply with the applicable regulatory framework (e.g. obtain export/import licences before these items are used).	☒
8) We confirm that the activities proposed do not - aim at human cloning for reproductive purposes; - intend to modify the genetic heritage of human beings which could make such changes heritable (with the exception of research relating to cancer treatment of the gonads, which may be financed), or - intend to create human embryos solely for the purpose of research or for the purpose of stem cell procurement, including by means of somatic cell nuclear transfer. - lead to the destruction of human embryos (for example, for obtaining stem cells) These activities are excluded from funding.	☒
9) We confirm that for activities carried out outside the Union, the same activities would have been allowed in at least one EU Member State.	☒

The coordinator is only responsible for the information relating to their own organisation. Each applicant remains responsible for the information declared for their organisation. If the proposal is retained for EU funding, they will all be required to sign a declaration of honour.

False statements or incorrect information may lead to administrative sanctions under the EU Financial Regulation.

2 - Participants

List of participating organisations

#	Participating Organisation Legal Name	Country	Role	Action
1	FONDAZIONE ISTITUTO ITALIANO DI TECNOLOGIA	IT	Coordinator	
2	UNIVERSITAET LEIPZIG	DE	Partner	
3	University of Fribourg	CH	Associated	
4	UNIVERSITAET HAMBURG	DE	Partner	
5	UNIVERSITEIT ANTWERPEN	BE	Partner	
6	KARLSRUHER INSTITUT FUER TECHNOLOGIE	DE	Partner	
7	KERR S.R.L	IT	Partner	
8	FUNDACIO INSTITUT CATALA DE NANOCIENCIA I NANOTECNOLOGIA	ES	Partner	
9	CNT Innovation	BE	Partner	

Organisation data

PIC	**Legal name**
999596447	*FONDAZIONE ISTITUTO ITALIANO DI TECNOLOGIA*

Short name: IIT

Address

Street	VIA MOREGO 30
Town	GENOVA
Postcode	16163
Country	Italy
Webpage	www.iit.it

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	no
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	12/04/2022 - no
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	DELTA Lab (Disruptive Energy Lab for Trailblazing Advancements)	☐ not applicable
	☒ Same as proposing organisation's address	
Street	VIA MOREGO 30	
Town	GENOVA	
Postcode	16163	
Country	Italy	

Links with other participants

Type of link	Participant

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Prof.

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Remo**

Last name*: **Proietti Zaccaria**

E-Mail*: **remo.proietti@iit.it**

Position in org.: Senior Researcher

Department: DELTA Lab (Disruptive Energy Lab for Trailblazing Advancements)

☐ Same as organisation name

☒ Same as proposing organisation's address

Street: VIA MOREGO 30

Town: GENOVA

Post code: 16163

Country: Italy

Website: www.iit.it

Phone: +xxx xxxxxxxxx

Phone 2: +xxx xxxxxxxxx

Other contact persons

First Name	Last Name	E-mail	Phone
Claudia	Schiaffino	claudia.schiaffino@iit.it	+xxx xxxxxxxxx
Projects	Office	projects@iit.it	+xxx xxxxxxxxx
Denis	Garoli	denis.garoli@iit.it	+xxx xxxxxxxxx

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier	
Prof	Remo	Proietti Zaccaria	Man	Italy	remo.proietti@iit.it	Category A Top grade re	Leading	7003339896	Other ID	Scopus
Prof	Denis	Garoli	Man	Italy	denis.garoli@iit.it	Category B Senior resea	Leading	0000-0002-5418-7494	Orcid ID	
Ms	Giulia	Crotti	Woman	Italy	giulia.crotti@iit.it	Category D First stage r	Team member	0000-0003-3976-9880	Orcid ID	
Mr	Andrea	Schirato	Man	Italy	andrea.schirato@iit.it	Category D First stage r	Team member	57201588782	Other ID	Scopus
Ms	Eleonora	Venezia	Woman	Italy	eleonora.venezia@iit.it	Category D First stage r	Team member	57208648406	Other ID	Scopus

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☒
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	**Short description (Max 500 characters)**
Publication	*R. Mupparapu, J. Cunha, F. Tantussi, A. Jacassi, L. Summerer, M. Patrini, A. Giugni, A.Alabastri, L. Maserati, D. Garoli, and R. Proietti Zaccaria, "High Frequency Light Rectification by Nanoscale Plasmonic Conical Antenna in Point-Contact-Insulator-Metal Architecture", Advanced Energy Materials 2022, 2103785* *Here we demonstrated the world record on visible light rectification by means of a plasmonic nanoantenna*
Publication	*B. Shkodra, M. Petrelli, M. Costa Angeli, D. Garoli, N. Nakatsuka, P. Lugli, and L. Petti, "Electrolyte-gate carbon nanotube field-effect transistors biosensors: principle and applications", Applied Physics Reviews 8, 041325 (2021)* *Invited review paper that involved multiple international experts in CNT-FETs*
Publication	*Bottom-Gate Approach for All Basic Logic Gates Implementation by a Single-Type IGZO-Based MOS Transistor with Reduced Footprint, Advanced Science 7, 1901224 (2020) -* *Here we have proposed the idea of single-type doped CMOS.*
Publication	*All-Optically Reconfigurable Plasmonic Metagrating for Ultrafast Diffraction Management, Nano Letters 21, 1345 (2021) -* *Here we demonstrate the numerical/theoretical capability of our group by developing the theoretical model of another publication of ours (Nature Photonics 14, 723 (2020)).*
Publication	*Transient optical symmetry breaking for ultrafast broadband dichroism in plasmonic metasurfaces, Nature Photonics 14, 723 (2020) -* *Here we shall show an example of nanofabrication realized within the IIT nanofabrication facility.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	**Short description (Max 500 characters)**
FET-OPEN DNA-FAIRYLIGHTS	*H2020 project on the development of radically new technology for DNA Data storage. This project will use DNA nanostructures to prepare DNA hard-disks able to store digital information in hybrid systems comprising DNA and nanomaterials. (IIT role - coordinator (R. Krahne and D. Garoli))*
MSCA DN - DYNAMO	*H2020 Doctoral Network Project. The project involves 9 international parterns for training and research programme on hybrid plasmonic nanostructures for single molecule manipulation, detection and sequencing (IIT role - coordinator (D. Garoli))*
ESA-OSIP	*European Space Agency project on the topic: Nanoresonators based sensors for Space.* *This is an activity that will consider CNT as one of the main building blocks for supporting the transition from micro to nanoscale at Space level. (IIT role - coordinator (R. Proitetti Zaccaria))*
ESA-OSIP	*European Space Agency project on the topic: Thermal energy generation in space: Improved thermoelectric performance via metamaterial technology. The idea is to develop metamaterials for managing heat due to radiations. (IIT role - coordinator (R. Proitetti Zaccaria))*
ESA-OSIP	*European Space Agency project on the topic: Plasmostor Digital Twin Technology and its impact to mitigate Space Radiation. Here a study on optical FET has been conducted. (IIT role - coordinator (R. Proitetti Zaccaria))*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	**Short description (Max 300 characters)**

Nanolithography facilities	*IIT is equipped with state-of-the-art nanofabrication tools. The group has several electrical characterization setups and several optical spectroscopy tools. It has full access to the Clean Room with major instruments for nanofabrication (https://www.iit.it/web/clean-room).*
Computational facility	*IIT has a dedicated facility with controlled humidity and temperature for accommodating high-performance workstations and dedicated personnel for their managing. The workstation we shall dedicate to the present proposal will be inserted in such a environment.*
Optoelectronic facility	*IIT offers a spectroscopy lab equipped with femtosecond pulsed laser sources, time-resolved photoluminescence (PL) spectroscopy and custom made setups for measuring amplified spontaneous emission and micro-PL. Photoconductive characterization relies on micromanipulator probe stations.*
Material characterization facility	*IIT offers a large characterization facility where several tools are available, such as: Transmission Electron Microscope (TEM), X-Ray Diffractometer, X-Ray Photoemission Spectroscopy (XPS), Raman, Atomic Force Microscopy, Multiprobe station for electrical measurements.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? (•) Yes ( ) No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
999854564	*UNIVERSITAET LEIPZIG*

Short name: ULEI

Address

Street	RITTERSTRASSE 26
Town	LEIPZIG
Postcode	04109
Country	Germany
Webpage	http://www.uni-leipzig.de

Specific Legal Statuses

Legal person	yes
Public body	yes
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	yes
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	31/12/2014 - no
SME self-assessment	31/12/2014 - no
SME validation	11/06/1999 - no

Departments carrying out the proposed work

Department 1

Department name	Peter-Debye-Institute for Soft Matter Physics	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Linnéstr. 5	
Town	Leipzig	
Postcode	04103	
Country	Germany	

Links with other participants

Type of link	Participant

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Prof.

Gender: ○ Woman ◉ Man ○ Non Binary

First name*: **Ralf** Last name*: **Seidel**

E-Mail*: **ralf.seidel@physik.uni-leipzig.de**

Position in org.: Principle investigator

Department: Peter-Debye-Institute for Soft Matter Physics ☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Linnéstr. 5

Town: Leipzig Post code: 04103

Country: Germany

Website: https://home.uni-leipzig.de/mbp/

Phone: +49 341 97 32501 *Phone 2* *+XXX XXXXXXXXX*

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Prof	Ralf	Seidel	Man	Germany	ralf.seidel@physik.uni-leipzig.de	Category A Top grade re	Leading	0000-0003-1330-8795	Orcid ID
Mr	Ulrich	Kemper	Man	Germany	ulrich.kemper@physik.uni-leipzig.de	Category D First stage r	Team member	0000-0002-4708-2416	Orcid ID
Dr	Nicole	Weizenmann	Woman	Germany	weizenmann@uni-leipzig.de	Category C Recognised	Team member		
Not applicab	To be hired	To be hired			unknown@uni-leipzig.de	Category D First stage r			
Not applicab	To be hired	To be hired			unknown@uni-leipzig.de	Category C Recognised			

Administrative forms

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☐
IPR management incl. technology transfer	☒
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	**Short description (Max 500 characters)**
Publication	*J Ye, S Helmi, J Teske, R Seidel. Fabrication of Metal Nanostructures with Programmable Length and Patterns Using a Modular DNA Platform. Nano Letters 2019, 19, 2707-2714*
Publication	*T Bayrak, S Helmi, J Ye, DJ Kauert, J Kelling, T Schönherr, R Weichelt, A Erbe, R Seidel. DNA mold templated assembly of conductive gold nanowires. Nano Letters 2018, 18, 2116-2123*
Publication	*R Weichelt, J Ye, U Banin, A Eychmüller, R Seidel. DNA-mediated Self-assembly and Metallization of Semiconductor Nanorods for the Fabrication of Nanoelectronic Interfaces. Chemistry 2019, 25, 9012-9016*
Publication	*J Ye, J Teske, U Kemper, R Seidel. Sequential Pull-Down Purification of DNA Origami Superstructures. Small 17, 2007218 (2021)*
Publication	*J Ye, O Aftenieva, T Bayrak, A Jain, T König, A Erbe, R Seidel. Complex metal nanostructures with programmable shapes from simple DNA building blocks. Advanced Materials 33, 2100381 (2021)*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	**Short description (Max 500 characters)**
cfaed - Cluster of Excellence (2015-2019)	*Consortium (funded by Deutsche Forschungsgemeinschaft) member within the BioAssembly path for self-assembly of nanoelectronic and nanooptical components*
DNA origami-bricks (2017-2020)	*Project funded by Deutsche Forschungsgemeinschaft (SE 1646 8-1) for the development of a verstaile DNA origami-brick system for the fabrication of nanoelectronic elements*
DNA origami molds (2013-2016)	*Project funded by the Deutsche Forschungsgemeinschaft within the Collaborative Research Center CRC-TRR61 regarding the preparation and self-assembly of noble metal nanoparticles with freely programmable shapes based on DNA origami molds*
MSCA DN-DYNAMO (2022-2026)	*Marie-Curie Doctoral Network (coordinated by IIT). Training and Research programme for the development of hybrid plasmonic nanostructures (DNA nanostructures+plasmonic nanopores/nanocavities) for single molecule manipulation, detection and sequencing*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	**Short description (Max 300 characters)**
Facility for Molecular Biology	*Essential laboratory facility containing bacterial culture, work places for molecular biology, centrifuges, shakers, incubators to allow production, handling and assembly of DNA (nanostructures) as well as the synthesis of metal nanoparticles*
Facility for gel electrophoresis	*Gel electrophoresis instruments and gel imaging at high sensitivity to analyze the assembly of DNA nanostructures*
TEM imaging	*Jeol JEM2100Plus transmission electron microscope for high resolution imaging of DNA nanostructures and attached nanomaterials (nanoparticles, nanorods etc). Selected area electron diffraction (SAED) allows the identification of deposited inorganic material layers.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◉ Yes ○ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
  - work-life balance and organisational culture;
  - gender balance in leadership and decision-making;
  - gender equality in recruitment and career progression;
  - integration of the gender dimension into research and teaching content;
  - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
911053877	*University of Fribourg*

Short name: University of Fribourg

Address

Street	Av. de l'Europe 20
Town	Fribourg
Postcode	1700
Country	Switzerland
Webpage	

Specific Legal Statuses

Legal person	yes
Public body	yes
Non-profit	yes
International organisation	unknown
Secondary or Higher education establishment	unknown
Research organisation	unknown

SME Data

Based on the below details from the Participant Registry the organisation is no **(small- and medium-sized enterprise) for the call.**

SME self-declared status	unknown
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Physics Department	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Chemin de Musée 3	
Town	Fribourg	
Postcode	1700	
Country	Switzerland	

Links with other participants

Type of link	Participant

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Prof	Guillermo	Acuna	Man	Argentina	guillermo.acuna@unifr.ch	Category A Top grade re	Leading	0000-0001-8066-2677	Orcid ID
Dr	María	Sanz Paz	Woman	Spain	maria.sanz@unifr.ch	Category C Recognised	Team member	0000-0002-6755-4476	Orcid ID
Mrs	Morgane	Loretan	Woman	Switzerland	morgane.loretan@unifr.ch	Category D First stage r	Team member	0000-0002-9920-5350	Orcid ID
Not applicab	To Hire	To Hire			unknown@unifr.ch	Category C Recognised			
Not applicab	To Hire	To Hire			unknown@unifr.ch	Category D First stage r			

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*G.P. Acuna, F.M. Möller, P. Holzmeister, S. Beater, B. Lalkens and P. Tinnefeld, ``Fluorescence Enhancement at Docking Sites of DNA-Directed Self-Assembled Nanoantennas", Science 338, pp. 506-510 (2012). First DNA origami self-assembly of nano-antennas for fluorescence enhancement. Highlighted in Nature Methods, ``Dye shines bright", Nature Chemistry,``Assembling nanoantennas" and Physik Journal, ``Fokussieren mit Gold". Selected for the Faculty of 1000.*
Publication	*K. Trofymchuk, V. Glembockyte, L. Grabenhorst, F., C. Vietz, C. Close, M. Pfeiffer, L. Richter, M.L.Schütte, F. Selbach, R. Yaadav, J. Zähringer, Q. Wei, A. Ozcan, B. Lalkens, G. P. Acuna and Philip Tinnefeld, ``Addressable nanoantennas with cleared hotspots for single-molecule detection on a portable smartphone microscope », Nature Communications 12, pp.950 (2021). Development of optical antennas based on DNA origami structures for bio-sensing applications on portable smart-phone microsco*
Publication	*K. Hübner, H. Joshi, A. Aksimentiev, F. D. Stefani, P. Tinnefeld and G. P. Acuna, ``Determining the In-Plane Orientation and Binding Mode of Single Fluorescent Dyes in DNA Origami Structures", ACS Nano 15, pp. 5109-5117 (2021). Determination of the orientation of single molecules incorporated to DNA origami structures by means of a combination of techniques including super-resolution DNA PAINT.*
Publication	*K. Hübner, M. Pilo-Pais, F. Selbach, T. Liedl, P. Tinnefeld, F. D. Stefani and G. P. Acuna, ``Directing Single-Molecule Emission with DNA Origami-Assembled Optical Antennas", ACS Nano 19, pp. 6629-6634 (2019). Development of optical antennas based on metallic nanoparticles incorporated onto DNA origami structures to mediate and direct the emission of single fluorophores.*
Publication	*A. Puchkova, C. Vietz, E. Pibiri, B. Wünsch, M. Sanz Paz, G.P. Acuna and P. Tinnefeld, ``DNA Origami Nanoantennas with over 5000fold Fluorescence Enhancement and Single-Molecule Detection at 25 μM", Nano Letters, 15 pp. 8354 (2015). Demonstration that DNA origami based nano-antennas could outperform lithographic nano-antennas in terms of fluorescence enhancement and single molecule detection.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
Project (see name in the description)	*"Single molecule fluorescence enhancement with self-assembled nanoantennas", G.P. Acuna and P. Tinnefeld, funded by the DFG (German Science Foundation) (2015). Study of DNA origami-based optical antennas for enhanced spectroscopies.*
Project (see name in the description)	*"Towards the development of next generation cellphone-based point-of-care diagnostic platforms", G. P. Acuna, funded by the DFG (German Science Foundation) (2015). Combination of optical antennas with smartphone based portable microscopes for the development of point of care diagnostics platforms.*
Project (see name in the description)	*"DNA self-assembled optical nano-antennas for single photon emitters. Directing and concentrating light for future diagnostic platforms", G.P. Acuna, funded by the SNSF (Swiss Science Foundation) (2019). Study of different materials including high-index dielectric materials for the development of low-loss optical antennas.*
Project (see name in the description)	*"Bioinspired DNA Self-assembly of nanophotonic devices", G.P. Acuna, funded by the SNSF through the NCCR Bio-Inspired Materials (2019). Study of different applications of bio-inspired materials for the development of meta-surfaces.*
Project (see name in the description)	*"ITN SuperCol: Rational design of super-selective and responsive colloidal particles for biomedical applications" European Consortium funded under H2020 (2020). Investigation of the effect of nanoparticles on the localization of single fluorophores in super-resolution microscopy.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
Wet lab	*Chemistry lab with all the required equipment for the synthesis and purification of DNA origami structures and the functionalization of nanoparticles, including thermocyclers, gel imager, centrifuges, nano-drop, fluorometer and UV-Vis-NIR spectrometer.*
Imaging Facilities I	*Our lab is equipped with a confocal time-resolved fluorescence microscope and a multicolor wide field (TIRF) fluorescence microscopy for super resolution imaging of the DNA origami structures. Our lab is also equipped with a dark-field microscope for imaging and characterization of nanostructures*
Imaging Facilities II	*Our group has granted access to the imaging facilities at the AMI Research Center located in campus and equipped with AFM, SEM and TEM devices for DNA Origami characterization, https://www.ami.swiss/en/research/facilities.html*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◉ Yes ◯ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
999905101	*UNIVERSITAET HAMBURG*

Short name: UHAM

Address

Street	MITTELWEG 177
Town	HAMBURG
Postcode	20148
Country	Germany
Webpage	http://www.uni-hamburg.de/

Specific Legal Statuses

Legal person	yes
Public body	yes
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	yes
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	26/01/2022 - no
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name: Department of Physics

☐ not applicable

☐ Same as proposing organisation's address

Street: Jungiusstrasse 9-11

Town: Hamburg

Postcode: 20355

Country: Germany

Links with other participants

Type of link	Participant

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title: Prof.

Gender: ◯ Woman ◉ Man ◯ Non Binary

First name*: **Roland**

Last name*: **Wiesendanger**

E-Mail*: **wiesendanger@physnet.uni-hamburg.de**

Position in org.: Full Professor

Department: Department of Physics

☐ Same as organisation name

☐ Same as proposing organisation's address

Street: Jungiusstrasse 11A

Town: Hamburg

Post code: 20355

Country: Germany

Website: www.nanoscience.de

Phone: +49 40 42838 5244

Phone 2: *+xxx xxxxxxxxx*

Administrative forms

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Prof	Roland	Wiesendanger	Man	Germany	wiesendanger@physnet.uni-hamburg.de	Category A Top grade re	Leading	P-9726-2016	Researcher ID
Dr	Stefan	Krause	Man	Germany	skrause@physnet.uni-hamburg.de	Category B Senior resea	Team member	0000-0002-0677-8468	Orcid ID
Dr	Elena	Vedmedenko	Woman	Ukraine	vedmeden@physnet.uni-hamburg.de	Category B Senior resea	Team member	0000-0002-5492-7042	Orcid ID
Mr	Jonas	Koch	Man	Germany	jokoch@physnet.uni-hamburg.de	Category D First stage r	Team member	0000-0001-9111-9493	Orcid ID
Dr	To hire	To hire			tohire@physnet.uni-hamburg.de	Category C Recognised	Team member		

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	**Short description (Max 500 characters)**
Publication	*Atomically resolved mechanical response of individual metallofullerene molecules confined inside carbon nanotubes, M. Ashino, D. Obergfell, M. Haluška, S. Yang, A. N. Khlobystov, S. Roth, and R. Wiesendanger, Nature Nanotechnology 3, 337 (2008)*
Publication	*Atomic-resolution dynamic force microscopy and spectroscopy of a single walled carbon nanotube: characterization of interatomic van der Waals forces, M. Ashino, A. Schwarz, T. Behnke, and R. Wiesendanger, Phys. Rev. Lett. 93, 136101 (2004)*
Publication	*Direct observation of confined states in individual metallic single wall carbon nanotubes, Th. Maltezopoulos, A. Kubetzka, M. Morgenstern, R. Wiesendanger, S. G. Lemay, and. C. Dekker, Appl. Phys. Lett. 83, 1011 (2003)*
Publication	*A radio-frequency spin-polarized scanning tunneling microscope, J. Friedlein, J. Harm, P. Lindner, L. Bargsten, M. Bazarnik, S. Krause, and R. Wiesendanger , Rev. of Scientific Instruments 90, 123705 (2019)*
Publication	*Direct measurement of the local density of states of a disordered one-dimensional conductor, C. Meyer, J. Klijn, M. Morgenstern, and R. Wiesendanger, Phys. Rev. Lett. 91, 76803 (2003)*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	**Short description (Max 500 characters)**
Hamburg Cluster of Excellence	*Advanced Imaging of Matter (including scanning probe microscopy and spectroscopy methods)*
DFG Collaborative Research Center 508	*Quantum Materials (including investigations by scanning probe spectroscopy)*
DFG Graduate School 1286	*Functional metal-semiconductor hybrid systems*
DFG project WI1277/23	*Spin-resolved electron transport through magnetic nanostructures studied by a low-temperature multi-probe-STM*
EU project HERCULAS HPRN-CT-2000-00031	*High resolution electrical characterization of ULSI and advanced semiconductor devices*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	**Short description (Max 300 characters)**
Multi-probe SPM system	*This instrument is required for nano-scale electrical characterization of samples and devices.*
Variable-temperature SPM system	*This instrument is required for nano-scale probing of electronic properties of samples and devices.*
Low-temperature SPM system	*This instrument is required for atomic-resolution structural characterization of samples and devices.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◉ Yes ○ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
999902870	*UNIVERSITEIT ANTWERPEN*

Short name: UANT

Address

Street	PRINSSTRAAT 13
Town	ANTWERPEN
Postcode	2000
Country	Belgium
Webpage	www.uantwerpen.be

Specific Legal Statuses

Legal person	yes
Public body	yes
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	yes
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	13/01/2022 - no
SME self-assessment	26/03/2019 - no
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Department of Physics	☐ not applicable
	☒ Same as proposing organisation's address	
Street	PRINSSTRAAT 13	
Town	ANTWERPEN	
Postcode	2000	
Country	Belgium	

Links with other participants

Type of link	Participant

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title Prof.

Gender (●) Woman ( ) Man ( ) Non Binary

First name* **Sofie**

Last name* **Cambre**

E-Mail* **sofie.cambre@uantwerpen.be**

Position in org. TTZAPBOF Research Professor

Department Department of Physics

☐ Same as organisation name

☒ Same as proposing organisation's address

Street PRINSSTRAAT 13

Town ANTWERPEN

Post code 2000

Country Belgium

Website https://www.uantwerpen.be/en/staff/sofie-cambre/

Phone +32 3 265 24 52

Phone 2 *+XXX XXXXXXXXX*

Other contact persons

First Name	Last Name	E-mail	Phone
Anne	Adams	anne.adams@uantwerpen.be	003232653028
Wim	Wenseleers	wim.wenseleers@uantwerp.be	003232652451

Administrative forms

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Prof	Sofie	Cambré	Woman	Belgium	sofie.cambre@uantwerpen.be	Category B Senior resea	Leading	0000-0001-7471-7678	Orcid ID
Prof	Wim	Wenseleers	Man	Belgium	wim.wenseleers@uantwerp.be	Category B Senior resea	Leading	0000-0002-3509-0945	Orcid ID
Not applicab	to be hired	to be hired			unknown@uantwerp.be	Category D First stage r	Team member		

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*J. Campo, S. Cambré, B. Botka, J. Obrzut, W. Wenseleers, J. A. Fagan, "Optical property tuning of single-wall carbon nanotubes by endohedral encapsulation of a wide variety of dielectric molecules", ACS Nano 15, 2, p. 2301 (2021)* *CNTs were filled with more than 30 different compounds which allows for tuning their optical and electronic properties. The methodology developed in this work will be essential for the p-(n-)type doped CNTs obtained through endohedral filling.*
Publication	*H. Li, G. Gordeev, O. Garitty, N. A. Peyyety, P. B. Selvasundaram, S. Dehm, R. Krupke, S. Cambré, W. Wenseleers, Reich, M. Zheng, J.A. Fagan and B.S. Flavel, "Separation of specific single enantiomer single-wall carbon nanotubes in the large diameter regime", ACS Nano 14, 948-963 (2020)* *Collaborative effort between KIT and UANTWERPEN to obtain single-chirality large-diameter CNTs. UANTWERPEN role: spectroscopic characterisation of the sorted large diameter CNTs.*
Publication	*S. van Bezouw, D. H. Arras, R. Ihly, S. Cambré, A. J. Ferguson, J. Campo, J.C. Johnson, J. Defillet, W. Wenseleers and J. L. Blackburn, "Diameter-Dependent Optical Absorption and Excitation Energy Transfer from Encapsulated Dye Molecules toward Single-Walled Carbon Nanotubes", ACS Nano 12 (7), 6881-6894 (2018)* *Filling of CNTs with dyes to photosensitize the CNTs. The characterisation developed in this work will be essential for the endohedral doping of CNTs.*
Publication	*S. Cambré, J. Campo, C. Beirnaert, C. C. Verlackt, P. Cool, W. Wenseleers, "Asymmetric dyes align inside carbon nanotubes to yield a large nonlinear optical response", Nature Nanotechnology 10, p. 248-252 (2015)* *Alignment and filling of dipolar dye molecules inside CNTs resulting in a large nonlinear optical response of the encapsulated molecules. These results will be essential for the endohedral doping of CNTs.*
Publication	*J. Defillet, M. Avramenko, M. Martinati, M. Á. López Carillo, D. Van der Elst, W. Wenseleers, S. Cambré, "The role of the bile salt surfactant sodium deoxycholate in aqueous two-phase separation of single-wall carbon nanotubes revealed by systematic parameter variations", Carbon 195, p. 349-363 (2022)* *Chiral sorting of SWCNTs by ATPE was investigated in detail, in particular the role of bile salt surfactants. These results will be essential for the structure sorting of the filled CNTs.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
ERC starting grant ORDERin1D for S. Cambré	*This ERC Starting grant focused on the filling of CNTs with many different compounds to form 1D arrays of molecules, and the sorting of CNTs by both aqeuous two-phase extraction and density gradient ultracentrifugation methods.*
Tunable pulsed and continuous wave laser facility	*This infrastructure funding was obtained for the extension of a laser facility to a versatile wavelength-tunable pulsed and continuous-wave (CW) laser platform operating from the ultraviolet to the infrared range of the optical spectrum, for enabling a wide range of advanced spectroscopic techniques and laser-based applications. this platform will be essential for the spectroscopic characterisation of the CNT samples.*
FWO infrastructure funding for EPR facility	*high-end electron paramagnetic resonance instrumentation for catalysis and materials characterization.* *This EPR instrumentation can be used to quantify the doping level of p-(n-)type doped CNTs.*

Excelence of Science (EOS) project: CHARMING	*Within this collaborative project with several research institutes in Belgium researches the integration of carbon nanomaterials in optical fibres for biomedical imaging and sensing. Our role is to synthesize filled CNTs with enhanced nonlinear optical properties.*
FWO project: Functional carbon nanotube hybrids	*This fundamental research project focuses on the synthesis and advanced characterisation of endohedrally functionalised CNTs, to enhance their electronic and optical properties.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	**Short description (Max 300 characters)**
High-end EPR instrumentation	*This EPR facility includes continuous-wave and pulsed X- and W-band (9.4 -94GHz) EPR instrumentation which will be used to characterize and quantify the doping level of endohedrally-doped CNTs.*
Hercules Ultracentrifugation facility	*Facility for ultracentrifugation at accelerations up to > 1000 000 g, with a wide variety of rotors, and possibilities for in situ spectroscopic characterization in density gradients.*
Widely tunable amplified laser facility	*World-wide unique facility including a femtosecond pulsed laser with picosecond laser amplifier and OPA, with fully continuous tunability from 300 - 10 000nm, for time-resolved and nonlinear spectroscopy.*
Tunable high-resolution resonant Raman facility	*High resolution triple Raman spectrometers with fully continuously tunable laser wavelength from 374 to 1100nm.*
Ultrasensitive IR fluorescenceexcitation setup	*Unique ultrasensitive IR fluorescence-excitation setup with liquid nitrogen cooled parallel detectors sensitive up to 2200nm.*
Hyperspectral IR fluorescence microscope	*Setup for hyperspectral IR fluorescence microscopy with 2D InGaAs and Si CCD detectors.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◉ Yes ◯ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	**Legal name**
990797674	*KARLSRUHER INSTITUT FUER TECHNOLOGIE*

Short name: KIT

Address

Street	KAISERSTRASSE 12
Town	KARLSRUHE
Postcode	76131
Country	Germany
Webpage	www.kit.edu

Specific Legal Statuses

Legal person	yes
Public body	yes
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	yes
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	14/01/2022 - no
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Institute of Nanotechnology	☐ not applicable
	☐ Same as proposing organisation's address	
Street	Hermann-von-Helmholtz-Platz 1	
Town	Eggenstein-Leopoldshafen	
Postcode	76344	
Country	Germany	

Links with other participants

Type of link	Participant

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title Dr

Gender ○ Woman ◉ Man ○ Non Binary

First name* **Benjamin** Last name* **Flavel**

E-Mail* **benjamin.flavel@kit.edu**

Position in org. Heisenberg Research Group Leader

Department Institute of Nanotechnology ☐ Same as organisation name

☐ Same as proposing organisation's address

Street Hermann-von-Helmholtz-Platz 1

Town Eggenstein-Leopoldshafen Post code 76344

Country Germany

Website https://www.int.kit.edu/flavel

Phone +49 72160826977 *Phone 2* *+xxx xxxxxxxxx*

Administrative forms

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Benjamin	Flavel	Man	Australia	benjamin.flavel@kit.edu	Category B Senior resea	Leading	0000-0002-8213-8673	Orcid ID
Not applicab	To hire	To hire			unknown@kit.edu	Category B Senior resea			

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☐
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*R. Nißler, L. Kurth, H. Li, A. Spreinat, I. Kuhlemann, B. S. Flavel, S. Kruss, Sensing with Chirality-Pure Near-Infrared Fluorescent Carbon Nanotubes, Analytical Chemistry, 93, 2021, 6446-6455. DOI: 10.1021/acs.analchem.1c00168.* *Demonstrated ability to exchange surfactant wrapped carbon nanotubes with ssDNA as required by this project.*
Publication	*H. Li, G. Gordeev, D. Toroz, D. Di Tommaso, S. Reich, B. S. Flavel, Endohedral Filling Effects in Sorted and Polymer-Wrapped Single-Wall Carbon Nanotubes, Journal of Physical Chemistry C, 125, 2021, 7476 – 7487. DOI: 10.1021/acs.jpcc.1c01390.* *Investigation of how endohedral filling of a CNT can influence the result of separation. These insights will be valuable when sorting (n- and p-type) doped CNTs in this project.*
Publication	*H. Li, G. Gordeev, O. Garrity, N. A. Peyyety, P. B. Selvasundaram, S. Dehm, R. Krupke, S. Cambré, W. Wenseleers, S. Reich, M. Zheng, J. A. Fagan, B. S. Flavel, The Separation of Specific Single Enantiomer Single-Wall Carbon Nanotubes in the Large Diameter Regime, ACS Nano, 14 2019, 948 – 963. DOI: 10.1021/acsnano.9b08244.* *Application of the pH modulated ATPE method to separate large diameter single chirality CNTs. These will be required for endohedral filling in this project.*
Publication	*H. Li, G. Gordeev, O. Garrity, S. Reich, B. S. Flavel, Separation of Small-Diameter Single-Walled Carbon Nanotubes in One to Three Steps with Aqueous Two-Phase Extraction, ACS Nano, 13 2019, 2567 – 2578. DOI:10.1021/acsnano.8b09579.* *Development of the pH modulated ATPE method for the simple separation of single chiral carbon nanotubes.*
Publication	*H. Li, G. Gordeev, S. Wasserroth, V. S. K. Chakradhanula, C. N. S. Kumar, F. Hennrich, A. Jorio, S. Reich, R. Krupke, B. S. Flavel, Inner and Outer Wall Sorting of Double Walled Carbon Nanotubes, Nature Nanotechnology, 12 2017, 1176 – 1182. DOI: 10.1038/NNANO.2017.207.* *Proven ability to separate double wall carbon nanotubes based on the electronic type of the inner and outer wall. This ability will be valuable when using new raw materials in the project.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
Counter Current Chromatography of Carbon Nanotubes	*Ongoing research project from the German Research Foundation to develop the large scale and automated separation of single chiral carbon nanotubes.*
Separation of Double-Walled Carbon Nanotubes	*Completed research project from the German Research Foundation to separate double walled carbon nanotubes based on the electronic type of their inner and outer wall.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
High Performance Counter Current Chromatography	*A HPCCC enables the in-line and continuous two-phase separation of carbon nanotubes. This is a new system to the research group (2021) and is currently under development.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◯ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

PIC	**Legal name**
924427946	*KERR S.R.L*

Short name: KERR S.R.L

Address

Street	Via Milano 174
Town	Bolzano
Postcode	39100
Country	Italy
Webpage	www.kerr-italy.it

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	31/12/2015 - yes
SME self-assessment	31/12/2015 - yes
SME validation	unknown

Departments carrying out the proposed work

No department involved

Department name *Name of the department/institute carrying out the work.* ☒ not applicable

☐ Same as proposing organisation's address

Street *Please enter street name and number.*

Town *Please enter the name of the town.*

Postcode *Area code.*

Country *Please select a country*

Links with other participants

Type of link	Participant

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title Dr

Gender ◯ Woman ◉ Man ◯ Non Binary

First name* **Andrea**

Last name* **Stona**

E-Mail* **andrea.stona@kerr-italy.it**

Position in org. Owne

Department Management

☐ Same as organisation name

☒ Same as proposing organisation's address

Street Via Milano 174

Town Bolzano

Post code 39100

Country Italy

Website www.kerr-italy.it

Phone +393468083618

Phone 2 +xxx xxxxxxxxx

Other contact persons

First Name	Last Name	E-mail	Phone
Sara	Groppi	sara.groppi@kerr-italy.it	+XXX XXXXXXXXX

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Andrea	Stona	Man	Italy	andrea.stona@kerr-italy.it	Category A Top grade re	Leading		
Mrs	Sara	Groppi	Woman	Italy	sara.groppi@kerr-italy.it	Category D First stage r	Team member		
Mr	Mattia	Vinante	Man	Italy	mattia.vinante@kerr-italy.it	Category D First stage r	Team member		

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☒
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☒
IPR management incl. technology transfer	☒
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☐
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
MEDSENS	*Electro-medical device for emergency medicine for hypothermal body condition. In cooperation with Eurac Research Institute.*
KK-Camera	*In cooperation with Kofler Inewa companies. Artificial intelligence low cost embedded system for ambient condition detection: rain, snow, human presence, car/track presence. All the machine learning engine is embedded in a low cost risc microprocessor. Communication protocol is based on LoRa physical layer and a custom TDM approach. This is part of the Bolzano Provinz grants for innovation in research and development of state of the art technology.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
AC-AC power generator	*1 KW AC power generator for high voltage. Able to generate 1kW of power from 30V a.c to 300 Va.c. The equipment is used to characterize microelectronic devices as ASIC and power MOSFET.*
High precision multimeter	*High precision multimeter High precision multimeter able to measure a.c. and d.c voltages and current, resistance and capacitance; used to characterize electronic devices.*
RLC multimeter	*Multimeter able to measure with high precision inductance, capacitance, resistance and the combination of these for various frequencies.*
Oscilloscope	*4 channel analog oscilloscope, 1GsPs, 1Mb cache.*
Logic analyzer	*32 channels logic analyzer with 1s frame buffer and PC interface.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◯ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	Legal name
999606923	*FUNDACIO INSTITUT CATALA DE NANOCIENCIA I NANOTECNOLOGIA*

Short name: ICN2

Address

Street	CAMPUS DE LA UAB EDIFICI Q ICN2
Town	BELLATERRA (BARCELONA)
Postcode	08193
Country	Spain
Webpage	www.icn2.cat

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	yes
International organisation	no
Secondary or Higher education establishment	no
Research organisation	yes

SME Data

Based on the below details from the Participant Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	20/01/2022 - no
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

Department 1

Department name	Phononic and photonic nanostructures group	☐ not applicable
	☒ Same as proposing organisation's address	
Street	CAMPUS DE LA UAB EDIFICI Q ICN2	
Town	BELLATERRA (BARCELONA)	
Postcode	08193	
Country	Spain	

Links with other participants

Type of link	Participant

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title

Gender ◯ Woman ◯ Man ◯ Non Binary

First name* **Clivia** Last name* **Sotomayor**

E-Mail* **clivia.sotomayor@icn2.cat**

Position in org. Please indicate the position of the person.

Department *Name of the department/institute carrying out the work.* ☐ Same as organisation name

☐ Same as proposing organisation's address

Street *Please enter street name and number.*

Town *Please enter the name of the town.* Post code *Area code.*

Country *Please select a country*

Website *Please enter website*

Phone *+xxx xxxxxxxxx* *Phone 2* *+xxx xxxxxxxxx*

Other contact persons

First Name	Last Name	E-mail	Phone
Emigdio	Chavez	emigdio.chavez@icn2.cat	+xxx xxxxxxxxx

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier
Dr	Emigdio	Chavez Angel	Man	Chile	emigdio.chavez@icn2.cat	Category B Senior resea	Leading	0000-0002-9783-0806	Orcid ID
Prof	Clivia M.	Sotomayor Torres	Woman	United Kingdom	clivia.sotomayor@icn2.cat	Category A Top grade re	Leading	0000-0001-9986-2716	Orcid ID
Dr	Marianna	Sledzinska	Woman	Poland	marianna.sledzinska@icn2.cat	Category B Senior resea	Team member	0000-0001-8592-1121	Orcid ID
Dr	Francesc	Alzina	Man	Spain	francesc.alzina@icn2.cat	Category B Senior resea	Team member	0000-0002-9783-0806	Orcid ID
Dr	to be hired	to be hired			unknown@icn2.cat				

Role of participating organisation in the project

Project management	☐
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☒
Co-definition of research and market needs	☐
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☒
Technology developer	☐
Testing/validation of approaches and ideas	☒
Prototyping and demonstration	☐
IPR management incl. technology transfer	☒
Public procurer of results	☐
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*J. Jaramillo-Fernandez et al., Highly-Scattering Cellulose-Based Films for Radiative Cooling, Adv. Sci. 9, 2104758, 2022. This work presents the use of a nanocellulose as cheap and green material for radiative cooling applications. The radiative cooling is a passive approach for thermal management that allow to cool down surfaces exposed to sun radiation without the need of any external energy source.*
Publication	*P Xiao et al, Anisotropic Thermal Conductivity of Crystalline Layered SnSe2, Nano Lett. 21, 9172–9179, 2021. This work present the first measurement of anisotropy of the thermal conductivity of SnSe2 layered. Moreover the mean free path distribution was also calculated using the experimental data.*
Publication	*M. Kasprzak et al., High-temperature silicon thermal diode and switch, Nano Energy 78, 105261, 2020. In this work demonstrated a single-material thermal diode operating at high temperatures. These results are relevant to a variety of applications, from thermal energy management and harvesting to thermal logic and more, all merged into a single CMOS-compatible platform.*
Publication	*M. Sledzinska et al., 2D Phononic Crystals: Progress and Prospects in Hypersound and Thermal Transport Engineering, Adv Funct Mat 30, 1904434, 2020. Invited review covering phononic crystals to illustrate applications in thermal management and phonon engineering*
Publication	*J Maire et al., Thermal properties of nanocrystalline silicon nanobeams, Adv. Funct. Mat. 32, 2105767, 2021. This work highlights how grain sizes corresponding to the mean free path of the main heat carriers can strongly affect thermal conduction and compete with the geometry. Unexpectedly, the thermal conductivity of nanocrystalline silicon thin films is reduced by a factor 8 compared with crystalline counterpart.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
Nanopoly (EU H2020 FET open GA 289061)	*This project focuses on controlling the impedance and parasitic elements in metamaterial-based integrated circuits by independently tuning electric permittivity and magnetic permeability to values impossible to achieve in natural materials.*
LEIT (EU H2020 ERG AdG, Action 885689)	*This project focuses on the development technology for very low-power and low-loss information transmission in nanoelectronic circuits based on using phonons as the information carriers.*
SIP (MINECO, Spain PGC2018-101743-B-I00)	*National project focused on the study photon-phonon interactions and thermal transport in nanoscale systems.*
Phenomen (EU H2020, FET open GA 753450)	*Project coordinated by ICN2 focused on the development of optomechanical devices operated in environmental conditions and compatible with CMOS technology.*
Mergin (EU FP7 FET-Energy GA 309150)	*Project coordinated by ICN2 focused to the use of silicon membranes as platform for energy harvesting.*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)
Brillouin light scattering	*Setup dedicated to the acoustic (elastic) characterization of materials. It has a frequency resolution of 100 MHz and it can detect phonon from 500 MHz to 1 THz.*
Asynchronous optical sampling	*Advanced pump-and-probe femptosecond setup with 30 fs pulse length a 1 GHz of repetition rate. The setup is capable of detecting reflectivity variations of 10^-6 which correspond to variation of <1 pm and provides time resolution of 10 fs.*

Raman spectroscopy	*Two micro Raman setup (Horiba T64000 and S&I Princeton monovista) optimized for UV-vis spectral ranges. The spectral resolution are in the order of 0.5 cm-1 with a frequency window of 3 to 5000 cm-1.*
Thermal characterization	*Three homemade setup dedicated to thermal characterization of materials: (i) three omega technique for bulk, films and liquids ; (ii) Frequency domain thermoreflectance for bulk, thin films and 2D materials and (iii) Raman thermometry for bulk, thin films, 2D materials and free standing structures*
Laser-Doppler vibrometer	*A scanning ultra high frequency laser Doppler vibrometer (Polytec UHF-120-SV) measuring frequencies from few Hz up to 2.4 GHz in both frequency and time domain.*
Simulation tools	*Modelling and simulation software including: COMSOL, MATLAB, CASTEP, Mathematica, Optiwave, FDTD, Gaussian. Experience with data mining and data analysis using Orange, Matlab and Python.*

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ◉ Yes ○ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Administrative forms

PIC	Legal name
886221392	*CNT Innovation*

Short name: CNAT

Address

Street	Rue des Colonies 11
Town	Brussels
Postcode	1000
Country	Belgium
Webpage	www.cnt-innovation.com

Specific Legal Statuses

Legal person	yes
Public body	no
Non-profit	no
International organisation	no
Secondary or Higher education establishment	no
Research organisation	no

SME Data

Based on the below details from the Participant Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

SME self-declared status	28/04/2022 - yes
SME self-assessment	unknown
SME validation	unknown

Departments carrying out the proposed work

No department involved

Department name *Name of the department/institute carrying out the work.* ☒ not applicable

☐ Same as proposing organisation's address

Street *Please enter street name and number.*

Town *Please enter the name of the town.*

Postcode *Area code.*

Country *Please select a country*

Links with other participants

Type of link	Participant

Administrative forms

Main contact person

This will be the person the EU services will contact concerning this proposal (e.g. for additional information, invitation to hearings, sending of evaluation results, convocation to start grant preparation). The data in blue is read-only. Details (name, first name and e-mail) of Main Contact persons should be edited in the step "Participants" of the submission wizard.

Title Dr

Gender (•) Woman ( ) Man ( ) Non Binary

First name* **Jelena**

Last name* **Aleksic**

E-Mail* **jelena.aleksic@cnt-innovation.com**

Position in org. Head of Innovation Strategy

Department CNT Innovation

☒ Same as organisation name

☒ Same as proposing organisation's address

Street Rue des Colonies 11

Town Brussels

Post code 1000

Country Belgium

Website *Please enter website*

Phone *+xxx xxxxxxxxx*

Phone 2 *+xxx xxxxxxxxx*

Other contact persons

First Name	Last Name	E-mail	Phone
Bojan	Boskovic	bojan.boskovic@cnt-innovation.com	+xxx xxxxxxxxx

Researchers involved in the proposal

Title	First Name	Last Name	Gender	Nationality	E-mail	Career Stage	Role of researcher (in the project)	Reference Identifier	Type of identifier	
Dr	Bojan	Boskovic	Man		bojan.boskovic@cnt-ltd.co.uk	Category A Top grade re	Leading	7004055020	Other ID	Scopus
Dr	Jelena	Aleksic	Woman		jelena.aleksic@cnt-ltd.co.uk	Category A Top grade re	Leading	0000-0001-9662-6857	Orcid ID	

Role of participating organisation in the project

Project management	☒
Communication, dissemination and engagement	☒
Provision of research and technology infrastructure	☐
Co-definition of research and market needs	☒
Civil society representative	☐
Policy maker or regulator, incl. standardisation body	☐
Research performer	☐
Technology developer	☒
Testing/validation of approaches and ideas	☐
Prototyping and demonstration	☐
IPR management incl. technology transfer	☒
Public procurer of results	☒
Private buyer of results	☐
Finance provider (public or private)	☐
Education and training	☒
Contributions from the social sciences or/and the humanities	☐
Other If yes, please specify: (Maximum number of characters allowed: 50)	☐

List of up to 5 publications, widely-used datasets, software, goods, services, or any other achievements relevant to the call content.

Type of achievement	Short description (Max 500 characters)
Publication	*B. O. Boskovic, K. K. Koziol, A. T. H. Chuang, 'Carbon Nanomaterial Synthesis by Chemical Vapour Deposition', in 2nd edition of Encyclopedia of Nanoscience and Nanotechnology (Edited by H. S. Nalwa), American Scientific Publishers, 2011, Vol. 12, 109-135).*
Publication	*O. Fontaine, B. Boskovic, Y. Ge, Nanomedicine as a business venture, Nanomedicine: Principles and Perspectives, Springer, 305-319, ISBN (Print)978-1-4614-2139-9, 2014.*
Publication	*B. O. Boskovic, Carbon nanotubes and nanofibres, Nanotechnology Perceptions, Vol. 3, 2007, 141-158.*
Publication	*B. O. Boskovic, V. Stolojan, R. U. A. Khan, S. Haq and S. R. P. Silva, Large-area synthesis of carbon nanofibres at room temperature, Nature Materials, Vol. 1, No. 3, 2002, 165-168.*
Publication	*J. Aleksic, P. Zielke, J. A. Szymczyk: Temperature and Flow Visualization in a Simulation of the Czochralski Process Using TLCs, Annals of The New York Academy of Sciences, Volume 972, 2002, 158-163.*

List of up to 5 most relevant previous projects or activities, connected to the subject of this proposal.

Name of Project or Activity	Short description (Max 500 characters)
M3DLoC	*EC H2020 760662 project (2018-2022) Additive Manufacturing of 3D Microfluidic MEMS for Lab-on-a-Chip applications (www.m3dloc.eu).*
TriAnkle	*EC H2020 952981 project (2021-2024) 3D BIOPRINTED PERSONALISED SCAFFOLDS FOR TISSUE REGENERATION OF ANKLE JOINT (www.triankle.eu).*
UltraWire	*EC FP7 609057 project (2013-2016) Ultra-Conductive Copper-Carbon Nanotube Wire (www.ultrawire.eu).*
Oyster	*EC H2020 760827 project (2017-2021) Open characterisation and modelling environment to drive innovation in advanced nano-architectured and bio-inspired hard/soft interfaces (www.oyster-project.eu).*
nTRACK	*EC H2020 761031 project (2017-2021) Multimodal nanoparticles for structural and functional tracking of stem cell therapy on muscle regeneration (www.n-track.eu).*

Description of any significant infrastructure and/or any major items of technical equipment, relevant to the proposed work.

Name of infrastructure of equipment	Short description (Max 300 characters)

Gender Equality Plan

Does the organization have a Gender Equality Plan (GEP) covering the elements listed below? ○ Yes ◉ No

Minimum process-related requirements (building blocks) for a GEP

- **Publication:** formal document published on the institution's website and signed by the top management
- **Dedicated resources:** commitment of human resources and gender expertise to implement it.
- **Data collection and monitoring:** sex/gender disaggregated data on personnel (and students for establishments concerned) and annual reporting based on indicators.
- **Training:** Awareness raising/trainings on gender equality and unconscious gender biases for staff and decision-makers.
- **Content-wise, recommended areas** to be **covered** and addressed via concrete measures and targets are:
    - work-life balance and organisational culture;
    - gender balance in leadership and decision-making;
    - gender equality in recruitment and career progression;
    - integration of the gender dimension into research and teaching content;
    - measures against gender-based violence including sexual harassment.

Proposal ID **101099125**

Acronym **3D-BRICKS**

3 - Budget

No.	Name of beneficiary	Country	Role	Personnel costs/€	Subcontracting costs/€	Purchase costs - Travel and substistence /€	Purchase costs - Equipment/€	Purchase costs - Other goods, works and services/€	Internally invoiced goods and services/€ (Unit costs- usual accounting practices)	Indirect costs/€	Total eligible costs	Funding rate	Maximum EU contribution to eligible costs	Requested EU contribution to eligible costs/€	Max grant amount	Income generated by the action	Financial contributions	Own resources	Total estimated income
1	Fondazione Istituto Italiano Di Tecnologia	IT	Coordinator	373,100	0	17,200	9,600	88,600	0	122125.00	610625.00	100	610625.00	610,625	610625.00	0	0	0	610625.00
2	Universitaet Leipzig	DE	Partner	235,000	0	8,000	0	55,000	0	74500.00	372500.00	100	372500.00	372,500	372500.00	0	0	0	372500.00
3	University Of Fribourg	CH	Associated	0	0	0	0	0	0	0.00	0.00	100	0.00	0	0.00	0	666,875	0	666875.00
4	Universitaet Hamburg	DE	Partner	261,200	0	8,000	75,000	55,000	0	99800.00	499000.00	100	499000.00	499,000	499000.00	0	0	0	499000.00
5	Universiteit Antwerpen	BE	Partner	222,000	0	8,000	0	50,000	0	70000.00	350000.00	100	350000.00	350,000	350000.00	0	0	0	350000.00
6	Karlsruher Institut Fuer Technologie	DE	Partner	264,450	0	8,000	0	50,000	0	80612.50	403062.50	100	403063.00	403,063	403063.00	0	0	0	403063.00
7	Kerr S.r.l	IT	Partner	202,000	0	8,000	0	6,000	0	54000.00	270000.00	100	270000.00	270,000	270000.00	0	0	0	270000.00
8	Fundacio Institut Catala De Nanociencia I Nanotecnologia	ES	Partner	163,557	0	8,000	43,000	0	30,000	53639.25	298196.25	100	298196.00	298,196	298196.00	0	0	0	298196.00

Administrative forms

Proposal ID **101099125**

Acronym **3D-BRICKS**

9	Cnt Innovation	BE	Partner	124,000	0	8,000	0	5,500	0	34375.00	171875.00	100	171875.00	171,875	171875.00	0	0	0	171875.00
			TOTAL	1,845,307	0	73,200	127,600	310,100	30,000	589051.75	2975258.75		2975259.00	2,975,259	2975259.00	0	666,875	0	3642134.00

Proposal ID **101099125**

Acronym **3D-BRICKS**

4 - Ethics & security

Ethics Issues Table

1. Human Embryonic Stem Cells and Human Embryos		Page
Does this activity involve Human Embryonic Stem Cells (hESCs)?	◯ Yes ◉ No	
Does this activity involve the use of human embryos?	◯ Yes ◉ No	

2. Humans		Page
Does this activity involve human participants?	◯ Yes ◉ No	
Does this activity involve interventions (physical also including imaging technology, behavioural treatments, etc.) on the study participants?	◯ Yes ◉ No	
Does this activity involve conducting a clinical study as defined by the Clinical Trial Regulation (EU 536/2014)? (using pharmaceuticals, biologicals, radiopharmaceuticals, or advanced therapy medicinal products)	◯ Yes ◉ No	

3. Human Cells / Tissues (not covered by section 1)		Page
Does this activity involve the use of human cells or tissues?	◯ Yes ◉ No	

4. Personal Data		Page
Does this activity involve processing of personal data?	◯ Yes ◉ No	
Does this activity involve further processing of previously collected personal data (including use of preexisting data sets or sources, merging existing data sets)?	◯ Yes ◉ No	
Is it planned to export personal data from the EU to non-EU countries? Specify the type of personal data and countries involved	◯ Yes ◉ No	
Is it planned to import personal data from non-EU countries into the EU or from a non-EU country to another non-EU country? Specify the type of personal data and countries involved	◯ Yes ◉ No	
Does this activity involve the processing of personal data related to criminal convictions or offences?	◯ Yes ◉ No	

5. Animals		Page
Does this activity involve animals?	◯ Yes ◉ No	

6. Non-EU Countries		Page
Will some of the activities be carried out in non-EU countries?	◉ Yes ◯ No	9-15
University of Friburg (FRI) (Friburg - Switzerland) is a partner of the project.		
In case non-EU countries are involved, do the activities undertaken in these countries raise potential ethics issues?	◯ Yes ◉ No	
It is planned to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)?	◯ Yes ◉ No	
Is it planned to import any material (other than data) from non-EU countries into the EU or from a non-EU country to another non-EU country? For data imports, see section 4.	◉ Yes ◯ No	9-15
Samples prepared according to the procedure described in the proposal will be exchanged between FRI and the other EU partners.		

The main samples will be solid substrates functionalized with materials such as artificial DNA-nanostructures (no ethics issues). To note: “Switzerland is not an EU country, but has been associated to Horizon 2020 and is an associated country for the Horizon Europe programme.” “Switzerland's ethics standards are compliant with EU ethics standards.” “Laboratories and infrastructure of the University meet local and federal safety requirements.”

Is it planned to export any material (other than data) from the EU to non-EU countries? For data exports, see section 4.	(•) Yes	( ) No	9-15

Samples prepared according to the procedure described in the proposal will be exchanged between FRI and the other EU partners. The main samples will be solid substrates functionalized with materials such as artificial DNA-nanostructures (no ethics issues). To note: “Switzerland is not an EU country, but has been associated to Horizon 2020 and is an associated country for the Horizon Europe programme.” “Switzerland's ethics standards are compliant with EU ethics standards.” “Laboratories and infrastructure of the University meet local and federal safety requirements.”

Does this activity involve low and/or lower middle income countries, (if yes, detail the benefit-sharing actions planned in the self-assessment)	( ) Yes	(•) No	
Could the situation in the country put the individuals taking part in the activity at risk?	( ) Yes	(•) No	
7. Environment, Health and Safety			**Page**
Does this activity involve the use of substances or processes that may cause harm to the environment, to animals or plants.(during the implementation of the activity or further to the use of the results, as a possible impact) ?	( ) Yes	(•) No	
Does this activity deal with endangered fauna and/or flora / protected areas?	( ) Yes	(•) No	
Does this activity involve the use of substances or processes that may cause harm to humans, including those performing the activity.(during the implementation of the activity or further to the use of the results, as a possible impact) ?	( ) Yes	(•) No	
8. Artificial Intelligence			**Page**
Does this activity involve the development, deployment and/or use of Artificial Intelligence? (if yes, detail in the self-assessment whether that could raise ethical concerns related to human rights and values and detail how this will be addressed).	( ) Yes	(•) No	
9. Other Ethics Issues			**Page**
Are there any other ethics issues that should be taken into consideration?	( ) Yes	(•) No	

I confirm that I have taken into account all ethics issues above and that, if any ethics issues apply, I will complete the ethics self-assessment as described in the guidelines How to Complete your Ethics Self-Assessment ☒

Proposal ID **101099125**

Acronym **3D-BRICKS**

Ethics Self-Assessment

Ethical dimension of the objectives, methodology and likely impact

The project does not involve animals or humans. No impact of the activities in terms of environmental damage, political or financial adverse consequences , etc. are expected.
Moreover, Switzerland is not an EU country, however Switzerland's standards in ethics, data protection and research integrity are compliant with EU standards. FRI is an active member of the research community in Switzerland and complies with national legislation.

Remaining characters 4561

Compliance with ethical principles and relevant legislations

The Department of Equipment and Logistics of FRI guarantees that the laboratories and infrastructures of the Physics Department meet the regulatory requirements concerning staff and environment safety.
In addition, the performed research does not use nanomaterials as defined by the Second Regulatory Review on Nanomaterials COM/2012/0572.

Remaining characters 4661

Administrative forms

Proposal ID **101099125**

Acronym **3D-BRICKS**

Security issues table

1. EU Classified Information (EUCI)[2]		Page
Does this activity involve information and/or materials requiring protection against unauthorised disclosure (EUCI)?	◯ Yes ◉ No	
Does this activity involve non-EU countries?	◯ Yes ◉ No	
2. Misuse		**Page**
Does this activity have the potential for misuse of results?	◯ Yes ◉ No	
3. Other Security Issues		**Page**
Does this activity involve information and/or materials subject to national security restrictions? If yes, please specify: (Maximum number of characters allowed: 1000)	◯ Yes ◉ No	
Are there any other security issues that should be taken into consideration? If yes, please specify: (Maximum number of characters allowed: 1000)	◯ Yes ◉ No	

[2]According to the Commission Decision (EU, Euratom) 2015/444 of 13 March 2015 on the security rules for protecting EU classified information, “European Union classified information (EUCI) means any information or material designated by an EU security classification, the unauthorised disclosure of which could cause varying degrees of prejudice to the interests of the European Union or of one or more of the Member States”.

[3]Classified background information is information that is already classified by a country and/or international organisation and/or the EU and is going to be used by the project. In this case, the project must have in advance the authorisation from the originator of the classified information, which is the entity (EU institution, EU Member State, third state or international organisation) under whose authority the classified information has been generated.

[4]EU classified foreground information is information (documents/deliverables/materials) planned to be generated by the project and that needs to be protected from unauthorised disclosure. The originator of the EUCI generated by the project is the European Commission.

3D Biofabricated high-perfoRmance dna-carbon nanotube dIgital electroniCKS (3D-BRICKS)

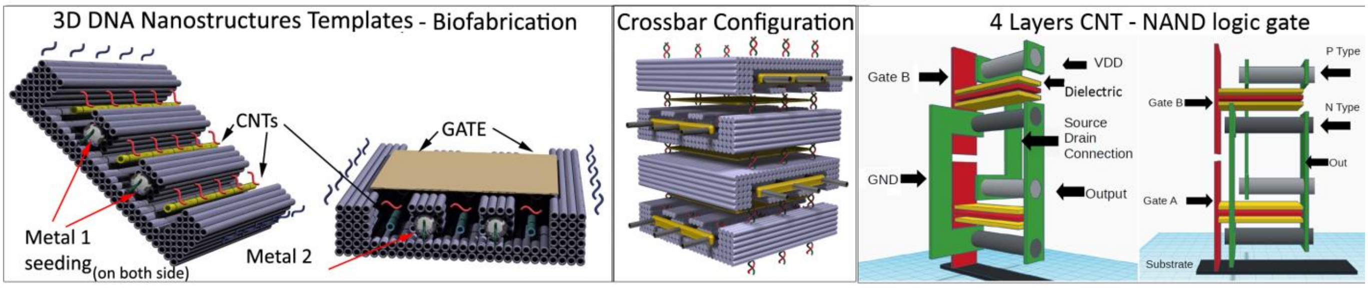

Figure 1. *Illustration of the **3D-BRICKS** concept (Self-assembly method; Multilayers CNT-FETs stack; Example of 3D logic gate)*

1. Excellence

1.1. Long-term vision

The new science-enabled technology of *3D-BRICKS* will provide a novel platform for the next-generation of electronic nanodevices (logics, digital circuits and memories). Hybrid DNA-nanostructures/carbon nanotubes (CNTs) will be developed for the realization of three-dimensional (3D) stacked transistors at high density, combined with a new series of designs for reproducing all the fundamental logic ports (*NOT, NAND, NOR and Flip-Flop Set Reset*) that will be fast, reliable and easily interconnected via planar (2D) and 3D configurations (**Fig.1**). Moreover, the same approach will be used to implement storage circuits (non-volatile memory) based on CNTs. The development of hybrid DNA/CNTs systems will be a paradigm change for nanoelectronics and computing, areas in which the current demand of new devices is rapidly outpacing the capabilities offered by semiconductor technologies. ***3D-BRICKS*** will also establish a highly versatile material platform that will boost several other nanobiotechnology sectors where optimized biofabrication can allow for new high-resolution nanofabrication solutions to be applied to neuromorphing computing, nano-sensors, data storage, cryptography, flexible devices and metamaterial systems.

3D-BRICKS will contribute to the development of new technologies for nanoelectronics based on *self-assembly of nanomaterials* by using biomolecule templates. The proposal will take advantage of the mature knowledge of DNA-based technology held by the consortium to go a step further and develop devices beyond the planar configuration. ***The development of nanomaterials with controlled properties and size, together with a self-assembly process on 3D DNA-nanostructure templates, will enable fast and large scale implementation of a new generation of electronics to perform computing at unprecedented level***. This will be a milestone for future nanoelectronics, where affordable materials and innovative methods will overcome the limitations in the current Si-based CMOS technology. The nanolithography-free *fully 3D design proposed in* **3D-BRICKS**, has the potential to radically transform the current approach in 3D transistor technology with a remarkable impact in nanoelectronics in particular and nanotechnology in general, fields that are expected to be worth more than $1,700 billion by 2030. Considering that the current electronics market is dominated by manufacturers located outside Europe, a strong action needs to be taken to strengthen the role of EU in the electronics sector. In this respect, in the long term it is envisioned that the technology developed in this project will become a game changer by shifting this balance in favour of Europe, with consequent beneficial economic and social impacts (new companies, jobs, inventions and education).

1.2 Science-towards-technology breakthrough

Targeted scientific breakthrough: ***3D-BRICKS* will pave the way towards the development of innovative CNT based 3D digital technologies.** It is anticipated that the continuous downscaling of silicon (Si) complementary metal–oxide–semiconductor (CMOS) devices is close to its end, but alternative technologies capable of maintaining advances in computing power and energy efficiency have not yet been established [10.1016/j.sse.2019.03.014]. In this respect, as the dimension decreases the effective thermal conductivity (k) also decreases, leading to large energy losses [10.1080/15567265.2015.1031857]. The reduction in k and the appearance of local hot spots can also severely degrade both the operational performance and long-term reliability of devices. CNT-based electronics is one of the most promising candidates to continue the downscaling [10.1126/science.aan2476; 10.1126/science.aaj1628; 10.1126/science.1065824]. Moreover, the robust thermal properties of CNTs offer an excellent platform for thermal management of the electronics components [10.1007/s10853-019-03368-0]. A range of methods has been developed to prepare high-purity semiconducting CNTs suitable for use in integrated circuits, and 5 nm CNT transistors with superior performance than Si-CMOS have been demonstrated [10.1038/s41928-019-0330-2]. CNTs offer extremely high carrier mobility and saturation velocity, which should provide high-speed device operation. They also allow a very high gate efficiency and thus a low supply voltage and high energy efficiency. The atomic thickness of the CNT body guarantees near-perfect electrostatic control of electrons movement in the nanotube which is expected to be free of short-channel effects hence providing excellent scalability [10.1109/TNANO.2004.842073]. *Computers based on CNT field-effect transistors (FETs) have been theoretically predicted to improve the power-performance by a factor of 10 compared to computers based on Si-CMOS technology* [10.1038/nature22994, 10.1016/j.mattod.2014.07.008]. However, the fabrication of high-performance CNT-FETs, and the realization of the full potential of CNTs, are extremely challenging [10.1038/s41928-018-0053-9]. Indeed, in order to achieve FETs with high performance and energy efficiency, evenly spaced semiconductor channels with small-pitch (where pitch refers to the spacing between two adjacent channels within an individual FET) are often required. Smaller channel pitch leads to higher integration density and on-state performance, and evenly spaced alignment minimizes the channel disorder that affects the switching between on and off states.

Biomolecules such as DNAs can be employed to organize CNTs into prescribed arrays [10.1021/acs.nanolett.0c02511] and biofabrication can scale the evenly spaced channel pitch beyond lithographic feasibility. However, none of the biofabricated CNT-FETs have exhibited performance comparable to the corresponding solutions constructed with lithography or thin-film approaches. Moreover, in biofabrication, the metal ions within biolattices and the sub-μm dimensions of typical biotemplates result in both poor transport performance and a lack of large-area array uniformity. To solve these issues, a rinsing-after-fixing approach to improve the key transport performance metrics in CNT-FETs has been demonstrated. The proposed method, that represents the state-of-the-art of CNT-FETs, also enables cm-scale alignment of CNTs in planar configurations [10.1126/science.aaz7435].

Additionally, the roadmap towards continuous downscale of minimum feature fabrication leads to innovative approaches based on FET designs in 3D. In particular, Intel was the first to introduce the *fin gate (also called a tri-gate) structure for MOSFETs* [10.1109/16.887014] in their 22-nm technology node. *The introduction of the 3D FinFET, that now represents the state-of-the-art of CMOS technology, created significant challenges in the fabrication processes*. The situation became even more difficult with the FET further scaling down to the 5-nm node, where nanowires and nanosheets had to be used as channels. As for Si-CMOS, CNT-based planar CMOS have been scaled down to sub-10 nm nodes, and CNT-based integrated circuits with performance comparable to Si-based 0.18 μm CMOS has recently been demonstrated [10.1038/s41928-017-0003-y]. However, as for Si-CMOS, huge fabrication challenges exist. The main one is obtaining well-aligned, all-semi-conducting, single-walled CNT films with high uniformity, high array density and low defect density on large wafers. The density required for CNT-FET is close to 150 CNT/μm, i.e. a spacing below 7 nm. *This is at the limit of the existing nanolithography technology and has not been achieved so far.*

In parallel to this, 3D CMOS technology has also greatly improved in the realization of solid-state non-volatile (NVM) memories. NAND flash is the mainstream NVM device of the modern electronics era. Advances in 3D NAND technology have enabled continued density scaling, however, challenges in fabrication and manufacturing have been hindering the extension of NAND technologies [http://semiengineering.com/how-to-make-3d-nand/]. In view of this and of the strong demand for higher-capacity memories, nanoscale random access memories that are based on hysteretic resistance changes (RRAMs) have gained great attention. Among the most promising examples of NVMs based on resistance changes, RRAMs capable to store terabytes of data with remarkable energy efficiency has been made possible through the use of carbon nanomaterials. CNTs have been proved to be a very valuable solution and crossbar memory configurations have been reported, also in the market [10.1021/nn401212p; 10.1109/MM.2019.2897560; 10.1038/natrevmats.2018.9; 10.1126/science.289.5476.94]. As for NAND CMOS technology, 3D CNT-RRAMs have been proposed [10.1109/NANO.2003.1231813], but as for the cases discussed above, the fabrication challenges are a major limitation.

In ***3D-BRICKS*** we will overcome the limits of nanofabrication for CNT nanoelectronic technologies *by introducing a radically new approach for using 3D DNA-nanostructures as template for transistors, digital logic gates and memories*. The main science-towards-technology breakthroughs are described in the following points:

- Biofabrication will be used to realize multilayer circuits (3D designs) through self-assembly approaches. The use of nanomaterials anchored along DNA nanostructures significantly reduces the complexity, time and cost of fabrication, with a spatial resolution close to the diameter of double stranded DNA (ca. 2 nm). A key aspect will be the use of in-series and in-parallel connections between different CNT transistors and circuits to create nanoelectronic components for computing.
- All the fundamental logic gates (NOT, NAND, NOR and Flip Flop Set Reset) and non-volatile memories will be prepared according to innovative 3D designs *enabling a element size reduction by a factor up to 4 with respect to the Si-CMOS logics.* Moreover, *the use of engineered (functionalized) CNTs (PIs Flavel, Cambré, Wenseleers) ensures the possibility to implement not only both p- and n- FETs logic gates but also single channel logics as recently demonstrated within the consortium (PI Proietti)* [10.1002/advs.201901224]. This latter solution, as explained below, can significantly reduce the complexity in the device fabrication.
- ***3D-BRICKS*** will develop a radically new approach to use biofabrication to complement the CNTs alignment in digital circuits with the self-assembly of metallic connections. In particular, *within the consortium (PI Seidel) we pioneered an unique DNA-mould based approach to self-assemble metallic nanoparticles with DNA-programmable shapes, i.e. metallic nanowires, nanoelectrodes to contact semiconducting* and organic materials as well as a modular platform to produce metal nanostructures with complex geometries including branched structures and networks in a highly versatile manner [10.1021/nl503441v; 10.1002/smll.202003662; 10.1002/adfm.201808116; 10.1021/acs.nanolett.9b00740]. Owing to these abilities it will also be possible to use multilayer 3D CNTs arrangements to realize nonvolatile memories (in particular RRAMs [10.1038/natrevmats.2018.9]).
- Applications of biofabrication in nanoelectronics are highly affected by material properties, such as conductivity, current distribution, thermal effects, charge transport behaviour, and surface potential [10.1021/acs.nanolett.0c02511]. We will employ scanning probe microscopy (SPM) that serves as "the eyes and the fingers" for nanostructure characterization. The 3D profile of a surface provided by SPM allows to examine a multitude of characteristics, including atoms arrangements, roughness, surface defects, and electronic properties. A technological breakthrough in ***3D-BRICKS*** will be the development of a characterization technology that will have application not only in planar nanostructures, but also in complex 3D nanomaterial arrangement. *Owing to the recognized expertise of the consortium (PI Wiesendanger)* [10.1126/science.1075302], we propose to dramatically improve the utility of SPM in 3D hybrid structures characterization by introducing a multi-tip SPM approach combining local electronic characterization with in-situ nanoscale transport measurements.
- Finally, this proposal will also explore the role of a well-known actor in electronic devices: heat. Although thermal effects are a well-known problem in electronics, full control over phonons, its main energy carriers, has not been achieved so far. Considering the large thermal conductivity of CNTs compared to Si-based devices at the same length scale, this action represents an excellent

opportunity to improve thermal management in nanoscale devices. Studies of thermal and acoustic properties in operando devices will be carried out thanks to the expertise within the consortium (*PI Sotomayor-Torres*) by using experimental and theoretical approaches [10.1063/1.4861796, 10.1021/acs.nanolett.1c03018]. The study of their acoustic properties under stress conditions will also provide valuable information for future stretchable devices [10.1021/acsaelm.0c00189].

1.3 Objectives

1.3.1. Specific main objectives

3D-BRICKS will reach 5 important objectives:

Objective /Milestone 1	*A set of novel designs for multilayer 3D CNTs integrated nanoelectronics considering both p- and n- FETs or single channel designs. The logic gates NOT, NAND, NOR and Flip Flop Set Reset will be designed and simulated. The use of 3D CNTs for storage circuits (non-volatile memories) will be also reported.*
Objective /Milestone 2	*A library of 3D DNA nanostructures with tailored geometry that can be linked at specific sites to functionalized nanomaterials, in particular to CNTs and metallic nanoparticles/nanowires.*
Objective /Milestone 3	*A set of robust protocols for the preparation, purification, selection and functionalization of SWCNTs. The CNTs will be prepared both with p- and n- doping and with controlled size. Additional set of SWCNTs will be prepared according to their use in non-volatile memories.*
Objective /Milestone 4	*Fabrication of a proof-of-concept platform for novel and ground-breaking nanoelectronic technology for hybrid DNA –CNTs computation based on multiple digital logics and storage circuits. The fabrication will be based, for the first time, on self-assembly methods where both semiconductor and metallic components will be integrated in multilayers.*
Objective /Milestone 5	*A set of tools for the characterization, with nanoscale precision, of the electrical and thermal properties of the 3D CNTs circuits.*

The objectives and associated milestones will be achieved following a detailed research approach, comprising sub-goals as described below (section 1.3.3). All will be directly measured by associated corresponding milestones. The tasks that will be performed to achieve the project's objectives, as described in section 3.2, comprise research & development activities well above the state-of-the-art and will generate, also individually, high impact results. Through the achievement of the 5 main objectives, the project will allow the following *key exploitable results*:

- IIT and KER: the definition, fabrication and test of a new set of nanoelectronic circuits which application can be extended not only to FETs and non-volatile memories, but in general to multiple fields (neuromorphing computing, nano-sensors, etc.).
- FRI and ULEI: the development of self-assembled bottom-up DNA platforms for hybrid functional devices that combine different species such as CNTs and metallic nanomaterials to form logic circuits and is readily scalable to 3D geometries.
- UANT and KIT: the combination of chiral sorting and endohedral filling for stable and controlled p- and n-type endohedral doping and functionalisation of CNTs which will not only be implementable in the here proposed electronics devices, but might find application in a much broader field, in particular in photovoltaics and nanophotonics devices.
- UHAM and ICN2: the combination of nanoscale transport and scanning probe microscopy techniques, thereby realizing the very local electronic characterization and imaging of nanocircuits and logic gates. This outstanding know-how in the field of nanoprobe technology will be developed in cooperation with the partners in WP6 and exploited as a future pay-per-use service.

1.3.2. High-risk research for achieving high-gain objectives

The ***3D-BRICKS*** proposal has all the following characteristics:

- **Long-term vision**: the research proposed addresses a new and radical long-term vision for a technology far beyond the state-of-the-art and currently not anticipated by technology roadmaps. *The involvement of several young or mid stage career scientists ensures a long term development* of the technology also after the end of the project.
- **Breakthrough S&T target**: our research project targets several crucial breakthroughs essential for the long-term goal, such as 3D nanoelectronics components designs; new 3D DNA nanostructures; reproducible control of nanomaterials functionalization; high performance and fully characterized devices. In particular, the most fundamental breakthrough will be a new approach for self-assembly of multilayer 3D nanoelectronics. This will open up a suite of new research avenues applicable to many fields, including material science, data storage, cryptography and nanophotonics.
- **High-risk**: the potential of our novel technology development proposal depends on a whole range of factors that cannot be apprehended from a single-discipline viewpoint. However, the self-assembly preparation of a set of 3D digital circuits will be extremely challenging and can only be realized by a highly skilled interdisciplinary consortium.
- **High impact**: The expected impact of ***3D-BRICKS*** is to initiate a radically new line of technologies by establishing the proof-of-concept of a multilayer 3D CNT based nanoelectronics. ***3D-BRICKS*** constitutes an early stage, high risk paradigm of visionary science and is based upon the collaborative research efforts of different participants, highly competent in their fields and motivated to a successful exploration of new founding principles.

1.3.3. Research Methodology

The research methodology is strictly oriented on the achievement of the objectives of the project. ***3D-BRICKS*** will combine the application of:

(i) *Innovative 3D transistors and memories designs -* (Objective 1)

(ii) *State-of-the-art DNA nanotechnology* - (Objective 2)
(iii) *Synthetic nanomaterials (CNTs)* - (Objective 3)
(iv) *Self-assembly of nanomaterials in 3D arrangements* - (Objective 4)
(v) *Deep comprehensions of the nanostructures' properties* - (Objective 5)

i. *The introduction of 3D arrangement of CNT-FETs for the realization of digital logics/circuits is the key-aspect of* ***3D-BRICKS***. In this respect, we shall employ a multiphysics approach for the design and numerical evaluation of 3D CNT-FETs/memories, whose performance will be determined against the employed materials and geometrical structure. Different 3D geometrical configurations will indeed be addressed, aiming at a reduced foot-print with respect to nowadays CMOS technology. In particular, the modelling will be employed to evaluate the impact of the channels size and different contact materials will be considered to minimize the Schottky barrier between CNT and metallic contacts. A deep investigation of the voltage thresholds of the device is mandatory to define the doping level (if any) of the CNTs and analyse the p-FET and n-FET structures, a study especially conducted through SPICE models. At the same time, also the time-response and the power consumption of the designed circuits will be addressed for example by minimizing the gate capacitance, one of the major obstacles to high-speed FETs, and through heat/temperature modelling, respectively. In particular, achieving a low enough power consumption would allow for an easy scale up of the number of gates. The pursued modelling strategy will rely on both commercial (Comsol) and open source (FEniCS, SPICE) solutions. The objective is to create a digital twin of the CNT-FET to identify and predict all its thermo-electro properties as a single unit or when implemented in a circuit. For example, we will be able to answer to questions such as: How close can the CNTs be one another? Open source flow will be preferred in order to open the technology to the community.

This kind of activity will be addressing both the single CNT-FET and, on a larger scale, *all the basic functional cells* (*NOT, NAND, NOR and Flip-Flop Set Reset*) and *storage circuits* (*CNT-nonvolatile memories*) in order to achieve *an entire working logic structure*. Importantly, all the designs will keep into account the biofabrication constrains described in this proposal. The objective is indeed to design elements/circuitry immediately manufacturable within the consortium. *As example*, for the simplest logic gate (the logic NOT), the consolidated planar CMOS approach requires a minimum number of 2 FETs, a n-FET and a p-FET. In ***3D-BRICKS*** a NOT cell with dimensions below 30nm x 30nm will be prepared thanks to a 2-layers in a 3D configuration (**Fig. 2a**). Finally, when it comes to 2-input Boolean logic gates, CMOS requires more than 2 n- and p- FETs, hence we expect that a 3D design arranging FETs in a vertical fashion could significantly reduce the size of the logic cell with consequent remarkable improvement in performance (**Fig. 1**). Last but not least, always aiming at a reduced foot-print, we shall employ single-type (only n-FET) CNT-based asymmetric gate FETs for realizing operating logic gates (see **Fig. 2b** for NOT) [10.1002/advs.201901224]. This approach will rely on the use of metals such as Sc, Y or Er for realizing a n-FET by employing either intrinsic or n-doped CNTs. Importantly, owing to the reduced material complexity with respect to standard CMOS approaches where both n- and p-type FETs must be employed, through this approach it can be conceived a 3D single-channel configuration when logic gates of the same kind should be connected in parallel/series. Together with the design of CNT-FETS, we will conceive 3D-nonvolatile memories. In particular, we shall extent the recently introduced concept of CNT 3D-RRAMs [10.1038/natrevmats.2018.9] by developing high spatial density memories that can be fabricated through the proposed self-assembly method. For example, crossbar RRAMs (**Fig. 1**) can be realized with CNT alignment promptly obtained by means of DNA-templates.

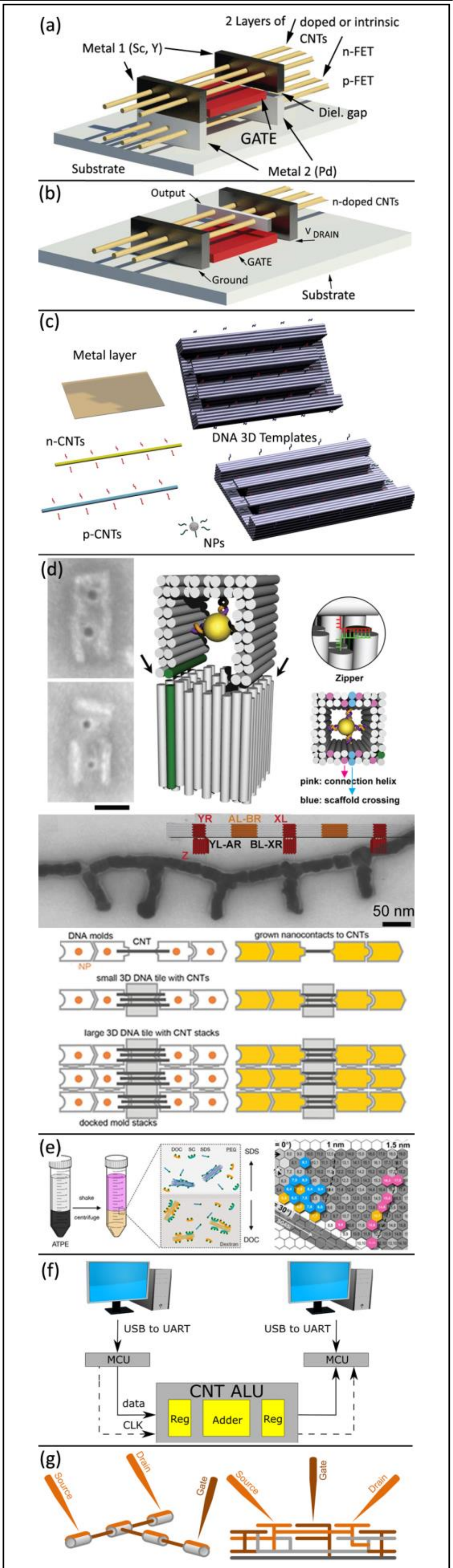

Fig. 2. a)3D CNT-NOT logic; b) single channel CNT-NOT; c)DNA-nanotechnology; d) ULEI metal deposition; e) APTE; f) POC computing; g)SPM for 3D analysis.

ii. *Development of novel concept for DNA nanotechnology and 3D nanoelectronics*: *Nanomaterial decorated (3D) DNA nanostructures* are a key component in ***3D-BRICKS***. We intend to significantly improve biofabrication protocols by guided assembly of nanomaterials on DNA templates and to revolutionize the much more challenging field of 3D CNT-FETs. It has already been demonstrated, within the consortium (PIs Acuna, Seidel) [10.1021/nl503441v; 10.1021/acsphotonics.7b01580] that complex DNA-origami and DNA-tile templates can be used to arrange nanoparticles and functional molecules at specific position. Moreover, it is possible to locally grow metallic nanoparticles and nanowires. We will extend these concepts by integrating nanomaterials with distinct properties in 3D schemes. This *use of DNA multilayer 3D nanostructures to prepare the skeleton of digital electronic components, in particular of FETs, to be self-aligned on the DNA template, represents a ground-breaking innovation in biofabricated nanoelectronics* (**Fig. 1, Fig. 2**). With this activity, we aim:

- To design a new set of DNA-nanostructures capable of integrating CNTs and other nanomaterials (metal NPs and nanowires) with nm precision and stoichiometric control in order to realize CNT-FETs, digital logics and non-volatile memories
- To increase the density of elements by stacking DNA-nanostructures in order to fabricate true 3D transistors and circuits

The DNA host structures will be designed featuring channels with anchoring sites where the CNTs that constitute the nanoelectronics components will dock through DNA hybridization, producing the desired geometry, alignment and CNT density. Additional sets of orthogonal binding sites will be introduced to allow the site-specific placement of DNA-functionalized metal seeds for the growth of local nanoelectrodes and to dock the DNA-origami host structures onto patterned surfaces to fabricate an array of FETs and circuits connections. Particular emphasis and attention will be paid to the modularity of the DNA-origami design. We will combine multilayers of these structures one on top of the other in a "sandwich" manner (**Fig. 1**), through for example DNA hybridization, in order to self-assemble a stack of layers each containing a DNA-origami structure decorated with CNTs and metallic contacts thus increasing the overall CNT density by exploiting the 3D capabilities of this approach. The design and stability simulation of these structures will be verified. Besides DNA-origami, other related techniques such as DNA-tiles and DNA-bricks will also be evaluated. The set of staples and scaffold strands will be acquired commercially and deposited on suitable substrates. As explained below, once a high level of homogenous DNA-origami structures is reached, we will proceed with studying the incorporation of previously functionalized CNTs through DNA hybridization and with the arrangement / controlled growth of metals within the structures.

iii. *Development of engineered nanomaterials for self-assembly in 3D-DNA*: The flexibility of the *CNTs synthesis, post-synthesis sorting, processing and endohedral functionalization is one of the key points* that we will exploit for successful 3D circuits fabrication. Two parameters still represent major challenges in CNT-electronics [10.1038/s41928-019-0330-2]: (1) the semiconducting versus metallic purity (determined by the number of CNTs on the chip – the metallic CNT content must be < 0.01 ppb), (2) the upper and lower limits of the CNT diameter (constrained by source-drain tunnelling and on-state resistance, respectively and determined by threshold voltage variation). Moreover, in the preparation of digital logics the use of n- and p- FETs is fundamental. The development of reliable methods for CNT sorting and processing, and for a good control in CNT doping can be a breakthrough advancement in CNT related applications. CNTs can be prepared with different aspect ratio. The use of different strategies for endohedral functionalization will allow to obtain the necessary doping. Here, we aim:

- To enhance the current method for post-synthesis sorting and processing of as-grown CNTs in order to obtain large quantity (mg) of CNTs with controlled properties.
- To investigate the application, in CNT-FETs and CNT-nonvolatile memories, of stable intrinsic and p- and n-doped CNTs.
- To demonstrate a protocol of external functionalization of these CNTs with the oligos used to self-assembly on the DNA templates.

The SWCNTs will be obtained commercially and successively processed. A process known as aqueous two-phase extraction (ATPE) will be used to separate the as-synthetized CNTs [10.1021/ja402762e]. In ATPE (**Fig. 2e**), the separation is sensitively related to the different solvation energy of two phases for CNTs which is controlled by surfactant coating and hydrophobicity [10.1021/nn405934y]. *As demonstrated within the consortium (B. Flavel, S. Cambré)*, by tuning the surfactant coating around the CNTs [10.1021/NN405934Y; 10.1016/j.carbon.2022.03.071] different chiralities can be sorted, and enantiomer pure fractions of CNTs with diameters of ≈ 1.4 nm and a single-chirality can be obtained. These large diameter SWCNTs are important building blocks for this project because the performance of CNT-FETs has been shown to be enhanced when using SWCNTs with a diameter > 1.2 nm. Furthermore the use of large diameter species ensures that the endohedral volume is large enough to encapsulate various dopant (n- and p-type) molecules. Essential to this chiral purification will be the characterization of the composition of the resulting samples. This can be achieved by a combination of dedicated spectroscopic techniques [10.1002/adma.200702353; 10.1021/acsnano.9b08244]. The proposed DNA nanostructures will also require CNTs with a narrow length distribution. Length separation will be achieved by exploitation of the length-dependent frictional coefficient of CNTs through a dense liquid (iodixanol) under centrifugation. Importantly this technique uses surfactant wrapped CNTs and is thus completely compatible with the ATPE process. With a CNT dispersion of controlled length, diameter, and electronic type in hand it will be necessary to exchange the surfactant wrapping around the CNTs with the DNA oligos. The n- and p- FETs will be built with sorted SWCNTs considering intrinsic doping. According to the literature, the use of different metals (in particular Pd, Sc and Y) for the source and drain contacts will enable to explore alternative properties [10.1016/j.mattod.2014.07.008]. The use of p- or n-type SWCNTs in 3D-FETs will be investigated. While typically SWCNTs are slightly p-doped, due to adsorption of oxygen on the SWCNT layers, n-type doping of CNTs is extremely difficult to achieve. One possible way of obtaining n-doped CNTs, is to replace the C-atoms with N-, however, this is certainly not a trivial pathway for CNTs. As demonstrated within the consortium (S. Cambrè) [10.1038/nnano.2015.1], a stable, *non-covalent and thus non-perturbing doping can be achieved by exploiting the inner hollow core of SWCNTs* and encapsulate *electron-donor and -acceptor molecules inside the SWCNTs.* Depending on the electron affinity or ionization potential of the encapsulated molecules, the doping level can be finely tuned. The results that will be obtained from the preparation of SWCNTs for 3D-FETs, will be the bases for their use in non-volatile memories, in particular the configuration most compatible with the proposed 3D self-assembly method is the crossbar RRAM where arrays of aligned CNTs are stacked one on top of each other [10.1038/natrevmats.2018.9] with orthogonal orientation. In this case, sorted ultralong (in the μm range) [10.1007/S12274-014-0680-Z] achievable through sonication-free processing will be properly functionalized to be integrated in the DNA-template.

iv. *Self-assembly of nanomaterials in 3D arrangements*: a radically new set of devices will be developed in several steps:

➢ A *planar configuration for single CNT-FET biofabrication* will be first reported [10.1126/science.aaz7435]. This will be a fundamental first step to optimize the functionalization of the processed CNTs to be complementary to the DNA channels. With respect to the state-of-the-art, both n- and p- FETs will be fabricated by using intrinsic SWCNTs and suitable contact metals. p- and n- doped CNTs will be tested in FETs. The length of the semiconductor channel will be tuned between 10 and 50 nm and the structure will be finalized with metallic and dielectric layers using nanolithographic processes (mainly electron beam lithography, physical vapour and atomic layer depositions). IIT, UHAM, ICN2 and KER will use suitable electrical contacts to test the FETs. The self-assembly approach for the fabrication of the metallic contacts thanks to the procedure developed in ULEI will then be tested. Although planar and 2-layers CNT-FETs have been already demonstrated, they are still based on complex multi-step fabrication processes [10.1038/s41586-019-1493-8]. Here, a *fully biofabricated CNT-FET will introduce a radical innovation with respect to the state-of-the-art*. A channel length below 10 nm will be obtained with DNA-template. While gold will be chosen at the beginning, other metals such *as Al, Pd, Sc, and Y,* will be used as metal contacts, these latter can be important in the realization of p- and n-FETs [10.1016/j.mattod.2014.07.008]

➢ In a *second stage* we will implement the multilayers 3D CNT-circuits platforms by using self-assembly of nanomaterials and molecular docking between multiple DNA nanostructures (**Fig. 1, Fig. 2**). In this case, the results obtained during the first phase will be implemented in multilayer designs. With this activity, we aim:

- To develop 3D nanostructures compatible with large array fabrication.
- To engineer the 3D CNT-FETs and 3D CNT-memories in order to obtain a high performance digital circuits.
- To integrate these smart nanostructures with on chip electronics for electrical data analysis and proof-of-concept computation.

State-of-the-art nanofabrication tools will be complementary used for for large-scale fabrication and prototype preparation. Key element is the development of nanomaterials preparation considering the different nature of the involved elements. A proper procedure to deposit dielectric layers within the different stacks will be obtained, in particular ALD after DNA rinsing will ensure conformal thin layer depositions of high index materials (such as HfO_2). The goal of 150 CNT/μm will be reached thanks to the multilayers arrangement, this very tight pitch allows for density scaling and source/drain contact scaling. The large-scale integration will be developed with strong input from the industrial partners. KER will investigate, and in case modify, the open source tool chain in order to provide the full path of development. This will involve schematic entry or Hardware Description Language (HDL) coding, pre layout simulation, synthesis, place and route (with clock tree insertion), post layout parasitic extraction and simulation. We will study different approaches including top-down techniques such as AFM, ion beam lithography together with parallelized techniques such as nanoimprint- lithography to fabricate binding sites. These techniques, which exhibit high spatial resolution surface modifications, will allow for the individual DNA origami host structures to be positioned and selectively oriented and enabling a large-scale integration [doi.org/10.1021/nn506014s; doi.org/10.1021/acsnano.1c01150].

It is important to underline that, *while an initial prototype comprising one or few logic ports will represent an outstanding outcome of the project, the ambitious goal of **3D-BRICKS** is to go further and demonstrate the fabrication of assemblies of a large number of FETs and nonvolatile memories*(over mm^2) that will ensure parallel digital data computation. In particular as a *final proof-of-concept goal*, to ***3D-BRICKS*** will setup a test gig in order to perform measurement on a real target application. The idea is to emulate an ALU inside a memory mapped load and store architecture of a microcontroller. As illustrated in a possible setup (**Fig. 2f**), the CNT-ALU is composed by a 32 bit adder fed by clocked registers controlled by a PC through microcontrollers. The results is stored in another microcontroller and back to the PC. *In this setup we can measure performance* of: (i) speed; (ii) stability vs temperature; (iii) propagation path efficiency; (iv) comparison between simulated environment and real measurements. In order to achieve this goal strategies to integrate both CNT-logic gates and CNT-RAMs will be developed and demonstrated.

v. *Study of downscaling effects in self-assembled CNT based circuits*. The downscaling of transistors brings some issues such as short channel effects, substrate depended phonon scattering and quantum confinements. While biofabrication is a valuable approach to overcome the lithographic limits, physical phenomena related to extreme downscale must be considered. In ***3D-BRICKS*** all these aspects will be considered and deeply investigated. *Being a completely new approach to the preparation of CNT transistors, we will require a new set of techniques and tools for the characterization of the proposed 3D structures.* While morphological, structural, thermal and acoustic properties of the nanomaterials used in the fabrication will be investigated by IIT, UANT and ICN2, the top level expertise within the consortium (PI Wiesendanger) will apply SPM techniques to the proposed 3D nanostructures (**Fig. 2g**). In order to characterize the multi-material devices, tools combining imaging, contacting and manipulation capabilities at unprecedented resolution ranging from the sub-μm down to the atomic-scale will be developed. To map ***3D-***

BRICKS complex network devices, we will confine the scanning to pre-defined areas and tunnelling conditions, thereby using the *probe tip as a pathfinder tool that explores the sample surface*. Resonant electron injection into image-potential states located above the surface of the device will be utilized for fast and reliable overview imaging. In contrast to conventional SPM, this method avoids the very close tip-to-sample positioning and potential tip collisions. Scanning at elevated bias voltages and tip heights will allow for a fast and reliable imaging. In-depth characterization in terms of atomic-resolution conventional SPM/STS will be performed with low-bias tunnelling on sites of interest. Finally, in order to define the electronic transport properties of the prepared devices, we will perform extended 3-tip SPM studies on 3D FETs, logic gates and memories. High-resolution thermal characterization of the devices under operation will be realized by mapping the emergent local temperature gradient between the sample surface and the scanning probe tip utilizing Seebeck tunnelling microscopy [10.1088/1361-6463/aacfab; 10.1126/science.aat7234]. Time-resolved experiments will be performed by sending ultrashort signals through the device and recording its response. With increasing complexity of the CNT-based device we will use the 3-tip SPM to characterize more sophisticated architectures, where input signals are processed in multi-level operations. Efforts will be made toward fundamental computational demonstrations relevant for future industrial applications of CNT-based nanoelectronics.

1.3.4 Gender dimension and other diversity aspects: The research and the expected goals of ***3D-BRICKS*** do not depend on gender aspects. Nevertheless, we will emphasize the importance of equal-opportunity attitude in all of our actions, especially in the outreach activities addressing the general public and trigger general discussions along the lines set forth in the Gender Innovations Project (http://genderedinnovations.stanford.edu/). Finally, 3 PIs over 9 partners are woman and the project's team will involve 50/50 woman/man personnel. The broad geographical spread of the nodes across EU assures a balanced character of ***3D-BRICKS*** at all levels of diversity.

1.3.5 Open science practices: The ***3D-BRICKS*** consortium is committed to integrate Open Science (OS) practices as early and widely as possible all along the project implementation. In particular, IIT and CNAT will coordinate the management WPs (WP1 and WP7) and both have experience working on creation of Open Innovation Environment on various projects and in publication of Open Access white papers related to open science (see for example zenodo.org/record/6363436#.YnEb-dpBy5c). At the same time ***3D-BRICKS*** will pursue a good balance between IP protection and openness to ensure the maximization use and impact of the obtained results. Open science is an approach based on open cooperative work and systematic sharing of knowledge and tools as early and widely as possible in the process. Open workflow will be fundamental to guarantee good Open Science Practice. The project commits to implement several OS practices:

Open Access (OA) to Published Research Results: The consortium will provide open access to all scientific publications relating to project results. Open access publishing venues (journals, conference proceedings, and books) will be preferred, when possible, to hybrid ones and the consortium will always negotiate to ensure to retain sufficient rights to comply with GA open access requirements. Targeted venues include: PubPeer; sharing preprints, e.g. at OSF, arXiv or bioRxiv. Peer-reviewed processes, especially open peer-review when available, will be favoured. In parallel, the consortium will deposit Author Accepted Manuscripts (or Version of Records) in a trusted repository (Zenodo, Dryad, or Dataverse) at the latest at time of publication, immediately providing open access to the publication under open licences (CC-BY and CC-BY-NC/ND). Publications' metadata will also be provided under CC0 public domain dedication or equivalent.

Open Research Data Management: Pending the necessary pre-screening to ensure the appropriate intellectual property (IP) protection data will be FAIR and made open when possible for access, reuse, and redistribution. Institutional repositories complying with FAIR principles (e.g. IIT Dataverse, Zenodo) will be used, if needed, for large datasets.

1.3.6 Research data management: ***3D-BRICKS*** will generate a significant amount of data that are meant to be conforming to the EC requirements, such as the Guidelines on FAIR Data Management, as well as to the International Reference Life Cycle Data system requirements. A Data Management Plan (DMP) will be prepared (IIT, CNAT). The DMP will: i) encompass information on how research data will be handled during and after the end of the project; ii) provide an analysis of the DM policy to be applied by the partners to datasets generated within ***3D-BRICKS***; iii) identify the main data to be generated within the project, outlining what parts of the data sets will be openly shared. The consortium has carried out a preliminary analysis of data to be generated within ***3D-BRICKS*** that are summarized in the following table:

Data	Partner	WP	Access	Stakeholder for potential re-use[1]
Circuit design (SPICE)	KER	2	Confidential	Electronics Industries / Sci. Comm.
DNA sequences / (.FASTQ)	FRI / ULEI	3	Confidential	Scientific community (Sci. Comm.)
Protocols for CNTs processing (.doc)	KIT/UANT/ICN2/UHAM	4-6	Public	Material scientists / Industries / Elec. Industries

The DMP will reflect the provisions established by the project contracts (Grant and Consortium Agreement) and will complement the project exploitation, dissemination and IPR procedures and decisions defined in several deliverables. Key data-management policies will be structured along the FAIR principles:

i) Findable Data: Clear naming conventions and versioning systems will be defined for all project datasets in order to guarantee the discoverability of data (for at least 5 years after the project end) alongside the use of DOIs.

[1] These stakeholder will be considered in dissemination activities

ii) Accessible Data: Selected data will be made openly available once cleared of any personal or organizational sensitive data (anonymized data) and if not violating any data privacy regulations. Data collected during the studies performed in the industrial scenarios will be also cleared of any information covered by intellectual property rights or ones that the company wants to keep confidential to not endanger the commercial exploitation of the proposed solution. After clearance, data will be stored in general Open Access repositories such as *Zenodo and EU cloud*, in partners' libraries, or in databases well established in the field.
iii) Interoperable Data: Metadata standards and schema such as Data Cite will be applied and well-established vocabulary will be used to allow data exchange and re-use. When possible, the consortium will use formats that are non-proprietary, unencrypted, uncompressed and in common usage by the research community.
iv) Re-usable Data: Public data will be made available for re-use and specific licences will be defined for each dataset in order to define all conditions under which the work is provided. The consortium will adopt different options among the Creative Commons License 4.0, guaranteeing at least the attribution requirement to appropriately credit the authors for the original creation.
v) Curation and storage costs: IIT will be responsible for the data management and quality assurance.

1.4. Interdisciplinarity ***3D-BRICKS*** proposes a technology concept that depends on a whole range of factors that cannot be apprehended from a single-discipline viewpoint. For this reason, the main characteristic of ***3D-BRICKS*** is the strong interconnection between different technological and scientific fields. The proposed research comprises applications of physics (electronics of nanostructures), chemistry (material synthesis and functionalization), biotechnology (molecular design and interaction, DNA assembly), bioinformatics (sequence analysis) and engineering (platform design and validation). ***3D-BRICKS*** establishes the collaboration of several top-level experts with a strong interdisciplinary approach. DNA-nanostructures will be developed by experts in bionanotechnology (FRI, ULEI) following designs prepared by experts in physics and nanoelectronics (IIT and KER). The DNA templates will be then decorated with nanomaterials optimized by chemists and material scientists (UANT, KIT) and the final devices will require a full characterization by means of advanced tools (UHAM, ICN2). To cross-finalize knowledge among partners, frequent exchange visits will be organized to the different labs.

2 IMPACT

2.1 Long Term Impact

3D-BRICKS proposes a novel concept of bioinspired digital electronics**:** the development of a *completely new 3D CNT integrated electronics solution*. While the use of DNA nanostructures to prepare planar integrated circuits is a demonstrated technology, the projection to third dimension to create multilayers high density digital circuits represents a significant and *non-incremental advancement* (only single aspects of this project have been validated in the lab, consequently the expected TRL is below 4).
Contribution to EU scientific leadership: ***3D-BRICKS*** unites the top excellence in DNA technology with those in nanomaterial and nanodevices fabrication, nanoscale precision characterization techniques, and nanoelectronics and thereby creates a unique opportunity to advance the EU role across these fields and to gain worldwide leadership. Moreover, through its strong interdisciplinarity, uniting materials sciences, electronics, and biotechnology the project will have a deep impact on EU science, since science is largely driven by new technologies that open the way to new insights and new concepts. From EU research perspective, the global visibility and competitiveness of the scientific partners will be strengthened, and will increase their chances to attract further large-scale funding. This again will boost the scientific advances of the EU research platform. The presence of 2 industrial partners in the project will ensure that consolidated progress in technology will be rapidly transferred to the established industrial networks, stimulating further commercialization prospects.
Contribution to EU society: *This proposal addresses an important technology that sees EU being far behind some actors such as USA, China, S. Korea and Japan*. In this respect, common perception among policy makers and consultants is that the EU industrial policy has underestimated the importance of industrial production and manufacturing for the economy. In fact, countries that have maintained a strong and competitive manufacturing base do much better than average during as well as after the crisis periods [10.1787/5k4869clw0xp-en]. In view of this situation, the EU Commission has identified 6 key enabling technologies which should drive the re-industrialization of EU, one of them being micro- and nano-electronics, in particular with *European Chip Act* [https://ec.europa.eu/commission/presscorner/detail/en/ip_22_729]. ***3D-BRICKS*** positions itself exactly at the edge of this technology, with the aim of contributing to the growth of EU electronics sector by proposing an innovative technological solution (disruptive innovation, 10.1038/s41586-019-0941-9). *Not less important,* ***3D-BRICKS*** *involves young PIs, key aspect to ensure a successful development of a radically new technology that can be expected to be ready in 10 years.* The success of this initiative will strongly improve the competitiveness of EU in this technological field, with the double effect of creation of a large number of new jobs (engineer, physicists, material scientists, etc.) and reducing the technological dependence from foreign countries. Finally, it is known that the scale of environmental impacts associated with the manufacture of microchips is characterized through analysis of material and energy inputs into processes in the production chain [10.1021/es025643o]. Advanced nanoelectronics produced with sub-10 nm resolution require very high power consumption, the processes proposed in ***3D-BRICKS*** can significantly reduce the complexity of production processes, hence impacting in the total energy use and the use of rare material components.
Contribution to EU industrial leadership – Technological / economic impact: The innovation capacity of ***3D-BRICKS*** is manifold, providing multiple avenues for increased competitiveness and industrial leadership that will help to address the global nanoelectronics challenges. A strong focus on technological developments will provide numerous commercial opportunities for the collaborating SMEs and industry, broadening the application spectrum of current products, extending product portfolios and providing a framework for key technological advances; advances which will push EU technological excellence into the spotlight

and improving industrial partners key performance and positioning within global markets. ***3D-BRICKS*** seriously address exploitation. By the end of the project a demo-application (described above ***Fig. 2f***) will be first demonstrated by KER, which will be also the first implementer of the technology. In the mid/long-term we expect that the project creates new market opportunities, strengthen competitiveness and growth not only of the involved SMEs but also to potential new spin-off companies related to the consortium. To meet the demand of new approaches for nanoelectronics, key EU companies as well as international enterprises, like Intel, ASML, IBM, and Apple (that are already looking beyond Si for solutions) will be approached and engaged in surveys and workshops. Information about their problems and needs will be collected and analysed (by CNAT) and used for development of ***3D-BRICK*** technologies and definition of most promising applications. The value of the global electronics market in 2019 was about $1.100 billion and it is expected to reach $2.300 billion by 2030 [www.alliedmarketresearch.com/nanotechnology-market]. Not less importantly, ***3D-BRICKS*** will also impact on CNTs market with new potential optimized materials and products. The global CNTs market attained $6 billion in 2020 and is expected to grow at a CAGR of 16% in the forecast period of 2020-2025 to reach $15 billion by 2026 [expertmarketresearch.com]. To enable further scale-up possibilities and ensure further funding, new calls with higher TRL will be mapped and presented to the partners, as well as government (e.g. ERDF, EIC accelerator, ECSEL) and private (venture capitalists such as Startup Autobahn, Forward31, 1886Ventures, M12 etc.) funding opportunities.

2.2 Innovation potential

During the whole project, special emphasis will be given on monitoring and identifying all knowledge created in the project that might have exploitation potential (CNAT). To support this, all knowledge created in the project will be tracked, collected, analysed and classified according to its nature (patenting potential, know-how, trade secret, service). An internal session dedicated to Key Exploitable Results identification, ownership and exploitation strategy will be organized. To assess the technology application potential, identify possible new markets and plan the market entry strategy, business architecture tools such as Value Proposition Canvas, SWOT analysis and market acceleration survey will be used. This will result in elaboration of a comprehensive market analysis report containing market trend, technologies, key-players, products and competitors' identification and analysis with performance assessments, technological benchmarking between project outcomes. The goal of this is to establish a breakthrough technology that will have a game changing impact on Europe's position on the global electronics market. This would contribute to economic growth and creation of new job opportunities across Europe. CNAT will organize an intellectual properties (IP) training workshop that will help partners to gain knowledge regarding IP measures and management. Special emphasis will be on patent exploitation strategy including licensing, spin-off company and Joint Venture. With the aim of empowering key actors in the field, extensive mapping of relevant stakeholders will be performed of which the key players will be identified. To further involve them in project activities, some of them will be invited to join the External Advisory Board. The mapped stakeholders (e.g. STMicroelectronics, NXP, IBM, Intel, ASML, Schneider Electric, etc.) will be asked to participate in an external survey that will be prepared and in the two stakeholders' engagement workshops that will be organized by CNAT.

In summary, the exploitation plan will include:

- An exploitation committee comprising all the PIs and external experts to be defined during the first year of the project.
- *Knowledge management and protection.* Up-to-date reviews of the state-of-the-art as well as novelty, patentability and IP protection analysis of the project results will be periodically performed during the ***3D-BRICKS*** lifetime. All issues relating to IP will be agreed upon within the consortium agreement before project start.
- Other relevant national, *EU and international projects and R&D initiatives* will be identified and *clustering actions* (for instance with other Horizon projects such as FET-Open DNA-Fairylights, MSCA-DN DYNAMO or 5D-Nanoimprinting where IIT is leading partner, two of them leaded by a PI of 3D-BRICKS) will be evaluated in order to identify common exploitation opportunities both at the EU and global level. A series of training activities will be designed and delivered during the project to ensure the transfer of knowledge within the consortium as well as to scientific, industry and other stakeholders.

2.3 Communication and Dissemination

a) Dissemination of results: ***3D-BRICKS*** dissemination efforts will be progressively increased as results are obtained. Key target groups will be the *scientific and technical communities related to nanotechnology* and *industrial stakeholders interested in bionanotechnology and nanoelectronics (international enterprises, like Intel, ASML, IBM, and Apple)*. The circulation of the project knowledge will be promoted, during the whole lifetime of the project, through the *project website*, by presenting the project results at *conferences* (SPIE, IEEE, CLEO, PIERS, NT series, etc.), *forums and symposia* (IWNC, etc.) as well as publishing them in scientific journals ('gold' open access journals – such as Nature, Science, Nano Letters, and others), according to the agreed publication policy. Finally, a ***3D-BRICKS*** open workshop will be organized at the end of the project to present the project results.
b) Communication activities: Communication activities will be strategically planned by the Communication Office (IIT) and Communication and Exploitation Office (CNAT) and implemented throughout the project duration, in order to maximize project awareness and promote its new ideas and concepts, its activities and events. Clear communication objectives and target audiences will be identified. ***3D-BRICKS*** will communicate its goals and activities and create awareness among the general public of the research work performed and its implications for citizens and the society. The ***3D-BRICKS*** consortium will continuously interact with the public through different communication channels regularly updated (see table below).
Finally, IIT and CNAT will coordinate a joint communication action aiming at reaching the main industrial (e.g. STMicroelectronics, NXP, IBM, Intel, ASML, Schneider Electric etc.) and financial stakeholders (such as Flashpoint Venture Capital, Earlybird Venture

Capital, BASF Venture Capital etc.) to define and organize a complete picture of the main micro/nanoelectronics oriented actors in EU. This will play a fundamental role for planning the following actions of 3D-BRICKS towards EIC Transition.

3D-BRICKS Website	Science Slams	Science Fun
• The project website will be used for communicating ***3D-BRICKS***'s goals and results in layman language. It will include summaries of the project, the latest research findings, and scheduled dissemination activities. It will feature a ***3D-BRICKS*** blog in which any exciting development on 3D Nanoelectronics (from the network or outside) will be highlighted monthly in a language accessible to the general public. To promote the project and the individual partner activities, a virtual exposition (https://www.medlocexpo.net/) will be created and linked to the project website. • *Target group*: General public, scientific community. • *Impact*: Increased interest for science, technology and basic research. • *Assessment*: Number of visits on the website and duration of stay; Feedback received from visitors and researchers.	• Each *PI* will develop a Science Slam on her/his research tasks. These 2-3-minute video pitches will be recorded and posted on the ***3D-BRICKS*** website and virtual exposition. Uploading to and promoting these videos on other social media platforms (e.g. YouTube, Linkedin) will provide an educational resource for a variety of end-users. • *Target group*: General public, teachers, school children. We will be effectively opposed to children's gender stereotypes. The girls will benefit from the positive role models of the female of the consortium. In this context the main goal is to improve the rather negative image of sciences among the secondary students and motivate them. • *Impact*: Increased interest for science, technology and basic research. • *Assessment*: Views on online platforms; experience feedback.	• ***3D-BRICKS*** will apply to organise a number of events in the European Researchers' Night dedicated to popular science and fun learning. Furthermore, several public events are regularly run at ***3D-BRICKS***'s participating sites. These include: annual Notte dei Ricercatori in Genova; "Nanotechnology exhibition" for the general public (nanotechnologie-ausstellung.de/) and "Nacht des Wissens" (Science night) in Hamburg; FRI will actively participate on several events like "Infodays" and "Explora" with high school students from the region including presentations, discussions and experiments (Friburg). ICN2 is part of ESCOLAB - open access to high school to the laboratories of the institution (Barcelona); studioSTEM - high schools visiting the research labs at UANT (Antwerp). • *Target Group*: General public, teachers, school children. • *Impact*: Increased knowledge about biotechnology and nanoscience. • *Assessment*: Number of visitors; online feedback form.

3 Quality and Efficiency of the Implementation

3.1 Quality of the consortium

The ***3D-BRICKS*** consortium was specifically assembled to unite the largely cross-disciplinary expertise that is crucial for the ambitious objectives on 3D CNT nanoelectronics, and to implement the developed technology in industry. For this project, the cutting-edge expertise in diverse fields is essential: (i) 3D FETs and digital logic/memory designs; (ii) innovative DNA nanotechnology, (iii) sorting and functionalization of nanomaterials with excellent electronic properties and size homogeneity; (iv) nanodevice and microchip fabrication for digital computing; (v) nm scale characterization tools. For each of these topics, the ***3D-BRICKS*** team can rely on a world leading expert group that will contribute with their specific expertise to the interdisciplinary goals. The G. Acuna group at FRI will provide the DNA nanotechnology pushing the design and synthesis towards 3D. The collaboration between FRI and R. Seidel (ULEI) will provide new DNA designs and methods to arrange nanomaterials, both CNTs and metals to the 3D DNA template. The already demonstrated strong collaboration between B. Flavel (KIT) and S. Cambré (UANT) will be the key for the development of engineered CNTs, pushing their doping and size control, and providing surface functionalization compatible with the oligo linking and fabrication steps. R. Wiesendanger (UHAM) and C. Sotomayor Torres (ICN2) will provide methods and tools for the hybrid DNA - 3D CNT nanostructures characterization and deep physical mechanism comprehension. R. Proietti Zaccaria and D. Garoli (IIT) contribute with the nanofabrication of the arrays and the electrical readout devices. ***3D-BRICKS*** will be balanced from a gender point of view. Two of the PIs are female ERC researchers (S.Cambré, C. Sotomayor Torres) and several groups have a gender ratio of 50/50 male/female, and as such we expect female scientists to play a significant role in this project. The project will benefit from involvement of 2 SMEs (KER, CNAT) which have a wealth of experience and expertise in micro and nanoelectronics applications and, as growing EU SMEs they will be also crucial for the exploitation management of the project's knowledge. KER will provide a new set of designs for 3D-circuits. CNAT (Jelena Aleksic), will support the team with a constant view towards market and final exploitation of the obtained results and inventions. In all the cases a close collaboration between the different partners is crucial since one technology will pass in the hands of the others and needs to be adapted to fit the requirements. This combined expertise across the different fields of nanoelectronics, material science, bionanotechnology, statistical physics, bioinformatics, information technology, and DNA nanotechnology is key for generating breakthrough discoveries and innovative science. In the detailed work plan, the consortium has defined a complex and complete framework of control points (deliverables, milestones and risks evaluation) to allow a punctual and continuous review of critical tasks and expected results. These control points will assure an assessment of the progress versus schedule and progress versus committed resources. All academic partners contribute with full access to their labs and infrastructure, and the

strong involvement of the PIs and senior postdocs of their groups. Work force hired on the project are mainly PhD students that will be supervised by the PIs. The SMEs will contribute with their personnel in the research and development units, and with the equipment and prototype machines that they have in their R&D labs. Details on the available facilities are reported in section A, in brief, the consortium can guarantee the access to state-of-the-art nanofabrication facilities (IIT, FRI, ULEI), to chemistry labs for material synthesis and processing (KIT, UANT) and to advanced characterization tools for material science, nanotechnology, nanobiotechnology and nanoelectronics (IIT, UHAM, UANT, ICN2, KIT).
Finally, the consortium will be governed by steering committee (all the PIs), exploitation board (leaded by CNAT and partners' innovation officers), technical committee (all WPs leaders).

Other countries: 3D-BRICKS will involve an affiliated partner from Switzerland (PI G. Acuna – FRI). The budget will be directly obtained from the affiliated country. Prof. G. Acuna will give an important contribution to the project thanks to his top-level expertise in DNA-nanotechnology, moreover, he is one of key scientists involved in the development of original 3D-nanoelectronics idea.

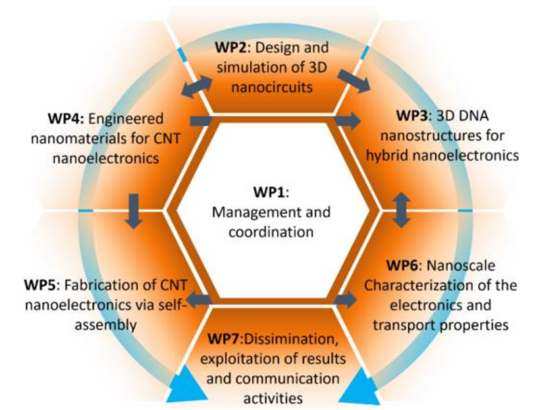

Figure 3. Graphical presentation of the components showing how they inter-relate (Pert chart).

3.2 Work plan

The project is planned over 36 months and it is implemented by adopting a step-by-step approach, which gradually increases in complexity. This concept guarantees the chances of success by assessing the optimized methodological and technological solution. The main objectives of the ***3D-BRICKS*** will be achieved thanks to the collaboration between the members of the consortium and by following a detailed approach programmed in inter-related 7 WPs and multiple tasks: (Fig. 3, Fig. 4).

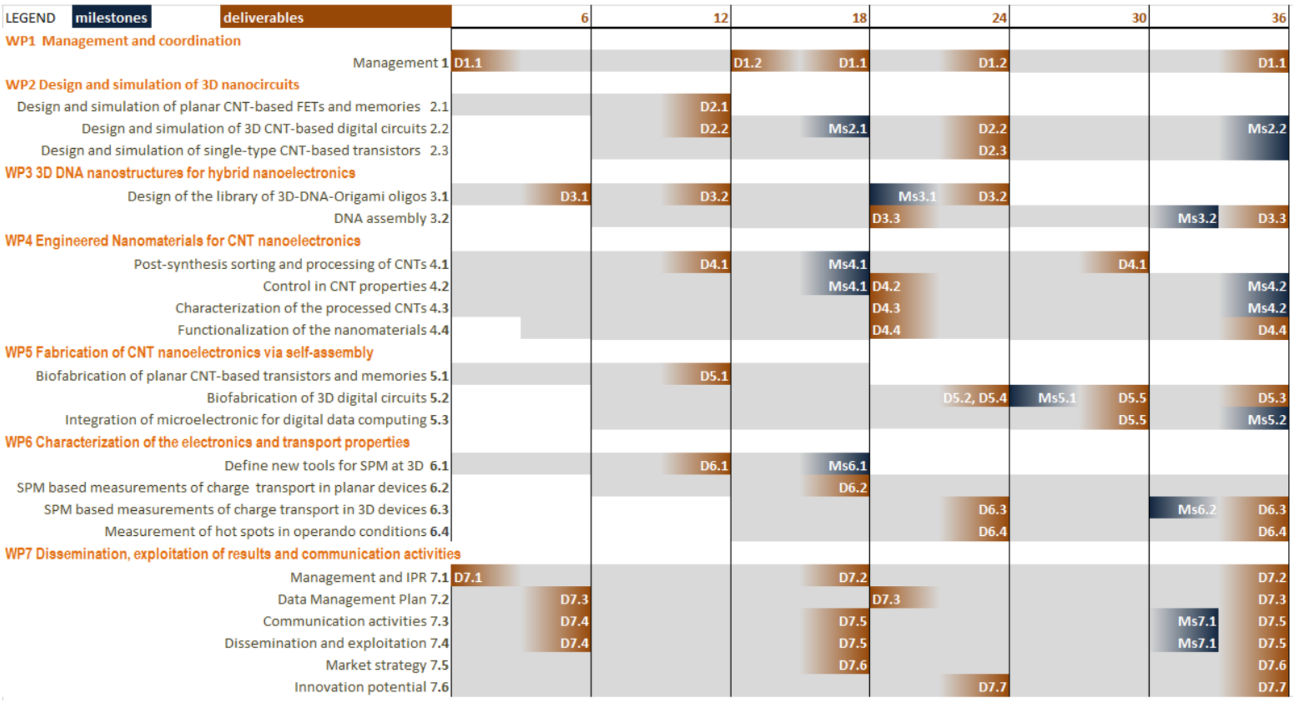

Figure 4 Timing of the different work packages and their components (Gannt chart)

Table 3.2a: List of work packages

Work Packages		Lead Partecipant		WP Leader	Gender	Start	End
Nr	Title	Nr	Name			M	M
1	Management and coordination	1,9	IIT, CNAT	R. Proietti Zaccaria, J. Aleksic	M, F	1	36
2	Design and test of 3D transistors, logics and memories	7	KER	A. Stona	M	1	36
3	3D DNA origami nanostructures for hybrid nanoelectronics	2,3	FRI, ULEI	G. Acuna, R. Seidel	M	1	36
4	Engineered Nanomaterials for CNT nanoelectronics	5,6	KIT, UANT	B. Flavel, S. Chambré	M, F	1	36
5	Fabrication of CNT nanoelectronics in self-assembly	1	IIT	D. Garoli	M	1	36
6	Nanoscale characterization of the electronic and transport properties	4,8	UHAM, ICN2	R. Wiesendanger, C. Sottomayor Torres	M, F	1	36

7	Dissemination, exploitation of results and communication activities	1,9	IIT, CNAT	D. Garoli, J. Aleksic	M, F	1	36

Table 3.2b: Work packages description

WP1	Management and coordination

OBJECTIVES

- Management and direction of the project (planning of resources, control of results and expenses, reporting to EU).
- Risk management, strategic re-allocation of resources, validation of major technical decisions.
- Prepare technical meetings, review meetings and contractual reports.
- Supervise exploitation process, including planning for technology implementation.

DESCRIPTION OF WORK

Task 1.1: Project Coordination *Task Leaders: Proietti Zaccaria and Garoli (IIT); participants: All PIs.*
Chair steering committee. Monitor overall project progress, coordinating risk management and resource re-allocation activities as appropriate. Approve reports. Organize project review meetings in contact to EU.
Task 1.2: Financial Management *Task Leaders: Proietti Zaccaria (IIT); participants: All PIs.*
Financial coordination, control and reporting on the distribution of the Community Financial Contribution, to include timely and accurate preparation and submission of cost statements.
Task 1.3: Technical and scientific coordination *Task Leaders: Proietti Zaccaria and Garoli (IIT), Aleksic (CNAT); participants: All PIs.* Chair technical committee, ensure efficient data exchange, organize online and in presence project meetings (~quarterly), prepare technical reports, review of state-of-the art, develop dissemination and use plan.

WP2	Design and simulation of 3D nanocircuits

OBJECTIVES

- To provide a set of designs of CNT-FETs and CNT-nonvolatile memories
- To provide a set of designs of 3D CNT-based digital logics and circuits
- To simulate and test the performances of the CNT-based electronics

DESCRIPTION OF WORK

Task 2.1: Design and simulation of planar CNT-FETs and memories *Task Leader: Stona (KER); participants: Acuna (FRI); Seidel (ULEI); Proietti Zaccaria (IIT), Chavez-Angel (ICN2).* Computer simulations will be performed on the single CNT-FETs (p-/n-doped and un-doped) in order to fully comprehend the properties of the system. A multiphysics approach will be employed, where the full thermo-electric properties of the transistor will be studied. This technique consists of realizing first an analog spice model for the CNT-FETs in order to characterize the behaviour of the logic port and a digital twin of the transistor by coupling together the differential equations governing the overall system. The performance of the transistor will depend on all its properties, i.e. material composition and geometry. Fundamental questions will be answered. For example, how do the height of the contact influence the current? What about the source/drain distance? How do reduce the local hot spots in operando conditions? In parallel to FETs design, RRAMs will be also simulated taking into consideration the high spatial density (pitch <5 nm) that can be achieved with biofabrication.
Task 2.2: Design and simulation of 3D CNT-based digital circuits *Task Leader: Stona (KER); participants: Acuna (FRI); Seidel (ULEI); Proietti Zaccaria (IIT).* Starting from task 2.1, 3D solutions specifically targeting the simplest logic gate, the inverter (**Fig. 2a**), will be developed. Afterwards, the remaining 3 logic ports, NAND, NOR and Flip-Flop will be designed and characterized in a 3D fashion and integrated in a full circuitry. Finally, 3D designs for nonvolatile memories will be verified.
Task 2.3: Design and simulation of 3D single-type CNT-based digital logic *Task Leader: Stona (KER); participants: Acuna (FRI); Seidel (ULEI); Proietti Zaccaria (IIT).* Here an exotic solution for designing logic gates will be adopted, only based on n-doped CNT-FETs. The game will be played on realizing “asymmetric” FETs (**Fig. 2b**) and their behaviour will be studied through HDL coding.

WP3	3D DNA nanostructures for hybrid nanoelectronics

OBJECTIVES

- To develop a new set of designs for 3D DNA nanostructures to be loaded with nanomaterials.
- To synthetize 3D DNA nanostructures to be deposited on solid substrates.

DESCRIPTION OF WORK

Task 3.1: Design of the library of 3D DNA Origami *Task Leaders: Acuna (FRI), Seidel (ULEI); Participants: Stona (KER)* DNA origami “host” structures will be designed using open source software in order to fulfil the requirements imposed by the desired 3D designs of the CNT-FETs, logics and circuits. This includes the capacity to incorporate CNTs and metallic nanoparticles at precise positions and orientations together with the ability to stack 2D DNA origami structures to form complex 3D geometries.
Task 3.2: Scalable DNA assembly *Task Leaders: Acuna (FRI), Seidel (ULEI)* The self-assembly conditions, including the annealing temperature, buffer and stoichiometry will be optimized in terms of the yield of properly folded structures using purification techniques such as gel-electrophoresis and imaging techniques such as AFM and electron microscopy.

WP4	Engineered Nanomaterials for CNT nanoelectronics

OBJECTIVES

- To establish a controlled procedure to process and sort SWCNTs with high purity and size control.

- To optimize the protocol of functionalization of CNTs to the oligos used to build the circuits on the DNA templates.
- To define a protocol to dope SWCNTs as p and n semiconductors
- To develop a set of functionalization strategies to link the nanomaterials with the 3D-DNA-nanostructures.

DESCRIPTION OF WORK

Task 4.1: Post-synthesis sorting and processing of CNTs *Task Leader: Flavel (KIT); participants: Cambré (UANT).* In ATPE, modulation of the SDS/DOC/SC ratio will be used to control the surfactant shell around the CNT and thereby the phase in which they are found. A new countercurrent chromatography setup (KIT) allows to optimize the variation of the many parameters involved in a more automated manner. The pH driven ATPE, developed at KIT, will be used to prepare enantiomer pure fractions with diameters of ≈ 1.4 nm and a single-chirality. Length separation will be achieved by centrifugation. While sorting will be mainly done at KIT, spectroscopic characterization of these large diameter CNTs will be performed at UANT, for which dedicated setups are available (e.g. IR fluorescence beyond 1650 nm).

Task 4.2: Control in CNT properties (doping) *Task Leaders: Cambré (UANT), participants: Flavel (KIT).* Doping by filling will be explored with molecules such as TCNQ and TTF, to molecules with higher or lower ionization potentials/electron affinities depending on the outcomes of these first fillers. The encapsulation can in principle provide a very stable doping. Also small molecular magnets will be encapsulated. Doping of the CNTs is expected to change the surfactant structure around them and ATPE protocols will need to be adapted for single chiral isolation and possibly even their exchange with ssDNA.

Task 4.3: Characterization of the processed CNTs *Task Leader: Wenseleers (UANT); participants: Chavez-Angel (ICN2), Flavel (KIT).* Different spectroscopic techniques will be used to characterize the processed CNTs, in particular to verify the filling through shifts and damping of the optical and vibrational properties of the SWCNTs, HRTEM to image the filling along the length of the CNTs but also analyze the composition (EELS), and RRS that can be used to assess the doping of the CNTS through a shift of the G-band, also electron paramagnetic resonance spectroscopy (EPR) will be employed as a quantitative tool to measure the doping levels of the resulting CNT hybrids and to verify the p- or n-type doping. Thermal transport properties of CNTs will be carried out by ICN2. Moreover the classification of the CNTs will be carried out by combination of spectroscopical analysis and statistical methods based on unsupervised models.

Task 4.4: Functionalization of the nanomaterials *Task Leader: Flavel (KIT); participants: Seidel (ULEI), Acuna (FRI).* Functionalization of CNTs and metallic nanomaterials can be readily achieved by engineered oligonucleotides with functional groups, or by using anchoring groups with carboxylic acid groups and EDC-NHS chemistry. For CNTs a procedure where DOC wrapped CNTs are mixed with PEG and the target ssDNA followed by the stepwise addition of methanol and isopropyl alcohol to precipitate the CNTs. Centrifugation is used to separate a nanotube pellet from the supernatant containing ssDNA dispersed CNTs. KIT has expertise in this procedure and recently used it to wrap specific single-stranded (ss)DNA sequences around monochiral small diameter CNTs. Metallic nanoparticles will be functionalized with ss-DNA oligos for later incorporation to the DNA origami structures for metal nanowire seeding following stablished protocols. Different purification techniques, will be studied to isolate the functionalized population of nanoparticles.

WP5	**Fabrication of CNT nanoelectronics via self-assembly**

OBJECTIVES

- To develop a biofabrication protocol for CNT-based transistors and memories.
- To develop a biofabrication protocol for CNT-based 3D digital logics
- To integrate these nanostructures with on chip electronics for digital data computing.

DESCRIPTION OF WORK

Task 5.1: Biofabrication of planar CNT-based transistors and memories *Task Leader: Garoli (IIT); participants: Acuna (FRI), Seidel (ULEI)* Once a high level of homogenous DNA-origami structures is reached, we will proceed with studying the incorporation of functionalized CNTs through DNA hybridization. In particular, we will adjust the number, length, and sequence of the anchoring sites and also perform temperatures cycles so that CNTs dock only at the pre-designed positions at the expected orientation. We will complement CNTs alignment with standard nanolithographic processes (mainly EBL and vapour depositions).

Task 5.2: Biofabrication of 3D digital circuits *Task Leader: D.Garoli (IIT); participants: R. Seidel (ULEI), G.Acuna (FRI)* We will proceed with the study and optimization of the incorporation of metals for contacts and with the sequential combination of DNA-origami structures to form 3D stacks. Finally, we will develop patterned surfaces with for example metallic islands matching the size of the DNA-origami structures where these can specifically bind via thiol modifications to form distinct arrays. A strong collaboration between IIT, FRI and ULEI will ensure the development of the radical new approach to move to 3D the design of DNA nanostructures for nanomaterials assembly and growth. Within the consortium ULEI will adopt its self-assembly scheme to allow the docking of CNTs into DNA moulds and the subsequent establishment of electric nanocontacts by metal plating inside of the moulds. We will incorporate 2D and 3D tile and origami assemblies carrying aligned CNTs at high densities into the mould assemblies. Starting with small tile structures this will allow to fabricate single CNT devices comprising multiple aligned CNTs. The added metal electrodes shall stabilize the CNT assembly even after removal of the DNA. If successful, we also aim for producing lateral stales of the mould assemblies, such that large DNA tile structures can be contacted by multiple nanoelectrodes. Suitable dielectric layers (mainly prepared with high-k materials such as HfO_2) will be included by means of serial atomic layer or physical vapour depositions.

Task 5.3: Large area fabrication and integration of microelectronic for digital data computing *Task Leader: A. Stona (KER); participants: D.Garoli (IIT), G.Acuna (FRI)* The biofabrication method will be complemented with standard lithography in order to prepare >mm² device. To characterize the performance (I-V curves measurements) of the prepared digital circuits suitable platforms will be developed via integration of the nanoelectronic circuits with metallic microconnections prepared by means of standard lithography.

WP6 Nanoscale characterization of the electronic and transport properties

OBJECTIVES

- Develop tools and protocols to characterize 3D hybrid biofabricated nanostructures
- Define the electronic transport properties of planar CNT-based transistors
- Define the electronic transport properties of 3D CNT-based nanoelectronics

DESCRIPTION OF WORK

Task 6.1 Define new tools for SPM at 3D *Task leader: Wiesendanger (UHAM)* A 3-tip SPM will realize a 3-terminal probe setup on the nm-scale, where each of the tips acts as a source, drain or gate of various signals, ranging from dc to RF bias. The free positioning of the probes on the device allows for the very controlled and precise measurement of its characteristics, even on the very complex circuits in 3D biofabricated structures. We will implement protocols that allow for a fast and reliable addressing of the different constituents for transport measurements and individual characterization in terms of SPM/STS.

Task 6.2 SPM based measurements of charge transport in planar biofabricated devices. *Task leader: Wiesendanger (HAM) Participants: Garoli (IIT), Acuna (FRI), Seidel (ULEI)* We will investigate the growth, alignment and quality of as-prepared sample systems. Electronic properties are studied by 1-tip STS, and functionalized wires will be tested under well-defined conditions in a 3-tip geometry. Contacting the CNT network with 2 tips, we will characterize the building blocks in terms of their charge transport properties. A third probe tip will be used to locally investigate the transport mechanism in terms of SPM/STS, and effects of tip-to-wire interactions onto the electron transport through the wire will be studied. Within the planar geometry of the hybrid devices, we will investigate the proximity-interaction between functionalized elements and CNT. Especially, gating a functionalized CNT with 1 probe tip and performing transport experiments on nearby CNT with 2 contact tips is envisaged, thereby potentially realizing a FET in the planar geometry. The dynamic response of the individual building blocks will be investigated by time-resolved transport measurements: RF signals will be sent through the wires, and their damping will be investigated as function of travel length and geometry of the wire, and effects of kinks and imperfections will be elaborated.

Task 6.3 SPM based measurements of charge transport in 3D biofabricated devices. *Task leader: Wiesendanger (UHAM) Participants: Garoli (IIT), Acuna (FRI), Seidel (ULEI)* We will extend the measurement protocols to 3D devices with defined interfaces and functional elements. For overview imaging we will use the procedures developed in Tasks 6.1 and 6.2, which will be extended to the 3D nature of the device. Here, complex 3D CNT networks will be investigated that provide numerous well-defined inputs, outputs and gating interfaces that will be used for a detailed characterization within our multiprobe SPM setup. The full SPM/STS capability of the setup allows not only for a direct measurement of the output signal – even parasitic effects like cross-talks to other elements in the close vicinity will be elaborated by parking the tip at various sites of interest.

Task 6.4: Measurement of hot spots in operando conditions. *Task leader: Sotomayor (ICN2)*. We will measure the power densities (hot spot) in operando conditions of designed and prepared circuits. We will use the large expertise of ICN2 on Raman thermometry to determine local hot spot (if there is any) in operando conditions.

WP7 Dissemination, exploitation of results & communication activities

OBJECTIVES

- Manage the knowledge and data generated during the project and define the IPR strategy for foreground protection
- Communicate the project ideas, activities, results, disseminate and exploit the scientific and technological breakthroughs

DESCRIPTION OF WORK

Task 7.1 Knowledge Management Activities and IPR strategy. *Task leader: Communication Office (IIT), J.Aleksic (CNAT); Participants: all partners*. This task will design and implement a plan for knowledge management and protection. Novelty, patentability and protection of the results will be periodically performed and level and methods of protections defined.

Task 7.2 Data Management. *Task leader: Project Office (IIT), J.Aleksic (CNAT); Participants: all partners*. Common procedures for the management of data generated during the project will be defined and implemented. A balanced strategy between i) open dissemination of results for maximizing access and re-use of data, and ii) protection of results for both privacy protection and market exploitation and patenting will be defined. Horizon EU Open Access Policy. The DMP will map all dataset generated by the project. The various acquired datasets will be distributed when possible via Open Data repositories and thematic platforms making sure third parties can freely access, mine, exploit, reproduce, and disseminate them. Should this not be possible for either IP protection or privacy reasons, clear opt out will be stated in the DMP and the collected results will be either shared internally to the consortium or kept by the developing partner.

Task 7.3 Communication activities. *Task leader: Communication Office (IIT), J.Aleksic (CNAT); Participants: all partners*. A communication plan will be drawn up and implemented. Activities within this task will include the set-up of the project website and virtual exhibition for internal and external communication, the creations of communication materials tailored to different target audiences (project logo, PowerPoint and Prezi presentations, reports, posters, leaflets, data sheets, fact sheets, press releases, video, infographics, images, schemas) as well as the development of a striking project image. The communication activity will also be extended to social media such (Twitter/Facebook/LinkedIn).

Task 7.4 Dissemination and Exploitation *Task leader: Communication and Project Office (IIT), J.Aleksic (CNAT); Participants: all partners*. A dissemination and exploitation plan will be drawn up and implemented. Activities within these tasks will include participation to scientific conferences and industrial forums (with both presentations and booths), publications on scientific journals and networking activities towards other national, EU and international projects and R&D initiatives always following the Open Access principles. A series of training activities will be also designed and delivered to ensure knowledge transfer. Training contents will be developed by the respective knowledge holders in the different fields and organized by IIT in clear knowledge transfer tools. Both internal and external training sessions will be organized as well as laboratory visits.

Task 7.5 Market entry strategy planning *Task leader: J.Aleksic (CNAT); Participants: all partners*. With the aim to initiate assessment of technology application potential and market entry strategy planning, CNAT will organize an internal Key Exploitable Results identification, ownership and exploitation strategy session. CNAT will use tools such as Value Proposition Canvas, SWOT analysis and internal exploitation and market acceleration survey in order to identify technology application potential to achieve transformative positive effect. A comprehensive market entry planning report will be prepared including market trend analysis, technologies, products, further funding opportunities, competitors' identification and analysis with performance assessments, technological benchmarking between project outcomes and the state-of-the-art and overall and individual exploitation strategies highlighting the key leverages to develop transformative and breakthrough technologies.

Task 7.6 Innovation and commercialization potential evaluation *Task leader: J.Aleksic (CNAT); Participants: all partners*. With the aim to initiate technology uptake and to understand future customers' problems and needs for solutions, we will map relevant stakeholders and engage them through an external survey and two stakeholders' engagement workshops. Collected information will be used for the preparation of Innovation and Commercialization Roadmap that will include innovation potential, IPR exploitation strategy, customer needs, customer demographics, identification of industrial areas and possible new market segments with long-term technology adoption analysis, technology and product positioning and analysis of competing solutions, science-towards-technology risk assessment, technology and applications roadmap development.

Table 3.2c: **List of Deliverables**

No.	Deliverable name	WP No.	Lead Participant	Type	Dissemi-nation level	Delivery date
D1.1	Technology implementation plan (TIP)	1	IIT	R	EU-C	M1, M18, M36
D1.2	Interim progress report (IPR)	1	IIT	R	EU-C	M12, M24
D2.1	Report on designs of planar CNT p-/n-FETs & memories	2	KER	R	EU-C	M12
D2.2	Report on designs of 3D CNT-circuits	2	KER	R	EU-S	M12, M24
D2.3	Report on single channel logics designs	2	IIT, KER	R	EU-S	M24
D3.1	Report on planar DNA origami design	3	FRI, ULEI	R	EU-C	M6
D3.2	Report on 3D origami design	3	FRI, ULEI	R	EU-S	M12, M24
D3.3	Report on DNA assembly characterization	3	FRI, ULEI	R	EU-C	M18, M36
D4.1	Report on CNT sorting and processing	4	KIT	R	EU-C	M12, 230
D4.2	Report on CNT doping	4	UANT, ICN2	R	EU-C	M18
D4.3	Report on CNT characterization	4	UANT, ICN2	R	PU	M18
D4.4	Report on material functionalization and metal seeding	4	KIT	R	EU-C	M18, M36
D5.1	Report on planar FETs and memories biofabrication	5	IIT	R	EU-C	M12
D5.2	Report on 3D - FET and memories fabrication	5	IIT	R	EU-C	M24
D5.3	Report on 3D digital logic biofabrication	5	IIT	R	EU-C	M36
D5.4	Report on CNT-FETs performances	5	IIT, KER	R	PU	M24
D5.5	Report on CNT-memories performances	5	IIT, KER	R	PU	M30
D6.1	Report on SPM tools design	6	UHAM	R	EU-C	M12
D6.2	Report on planar CNT-circuits SPM characterization	6	UHAM	R	EU-C	M18
D6.3	Report on 3D CNT-circuits SPM characterization	6	UHAM	R	EU-C	M24, M36
D6.4	Report on 3D CNT-circuits thermal characterization.	6	ICN2	R	EU-C	M24, M36
D7.1	Project Website	7	IIT	DEC	PU	M1
D7.2	Report on knowledge and IPR	7	IIT	R	EU-C	M18,M36
D7.3	Data Management Plan	7	IIT	DMP	EU-C	M6; M20; M36
D7.4	Plan for dissemination and exploitation including communication activities	7	IIT	R	EU-C	M6
D7.5	Report on dissemination and communication activities	7	IIT	R	PU	M18,M36
D7.6	Market entry planning	7	CNAT	R	EU-C	M18, M36
D7.7	Innovation & commercialization landscape –stakeholders	7	CNAT	R	EU-C	M24, M36

Table 3.2d: List of milestones

Ms Nr.	Milestone name	WPs	Due date	Means of verification
Ms2.1	fundamental digital ports 3D + nonvolatile memory designs available	2	M18	Schematics and simulations of the functionality of NOT, NAND, NOR, Flip Flop, non-volatile memory
Ms2.2	4 fundamental single channel logics designs available	2	M36	Schematics and simulations of single channel CNT-logics (NOT, NAND, NOR, Flip Flop)

Ms3.1	DNA structures library available	3	M18	DNA sequences and protocols to achieve 3D nanostructures and selective functionalization
Ms3.2	Large scale 3D DNA structures	3	M36	>mm² 3D biotemplates
Ms4.1	SWCNTs with high purity available	4	M18	Intrinsic semiconductor CNTs with metallic fraction <0.01ppb (single chiral)
Ms4.2	n- and p- doped SWCNTs available	4	M36	SWCNTs doped as p- and n- semiconductors
Ms5.1	3D digital logics fabricated	5	M24	Performance tests on biofabricated 4 Boolean logics
Ms5.2	POC - Arrays of logic ports for parallel computing	5	M36	Tests of computation from multiple ports connected – Proof-Of-Concept demonstrator
Ms6.1	3D SPM tool available	6	M18	Functionality of the new characterization tool
Ms6.2	Transport and electronics properties demonstrated	6	M36	Performances, at the nanoscale, of the fabricated nanoelectronics elements
Ms7.1	3D-BRICKS open workshop	7	M36	Final project workshop

The technologies used for ***3D-BRICKS*** are innovative and novel. Therefore probably not all risks can be estimated prior to project start. However, possible risks will be detected by ***3D-BRICKS*** as early as possible and corresponding actions will be taken.

Table 3.2e: **Critical risks for implementation**

DESCRIPTION OF RISK	WPs	PROPOSED RISK-MITIGATION MEASURES
Limit in Boolean logics 3D designs (Likelihood M; Severity M)	2,3, 5	If more than 2 layers designs will be not possible, the minimum outcome will be 2 layers designs with parallel planar connections. Single channel designs will enable to reduce the complexity and size of the CNT-FETs without the need of multilayer configurations.
Limitation in multilayers DNA nanostructures design and assembly (Likelihood M; Severity L)	3	Two layers DNA structures have been demonstrated also by the PIs and the self-assembly fabrication of n- and p- FETs in 2 layers still represents a significant result with respect to the state-of-the-art.
Limitations in complementary DNA functionalization with CNTs and metals (Likelihood M; Severity M)	3, 4,5	Links between Au and Pd with semiconductors by means of DNA have been demonstrated by ULEI, the use of alternative metals (Sc, Y) could require standard nanolithographic and nanofabrication steps.
Complex integration of dielectric layers in the 3D-CNTs circuits (Likelihood M; Severity M)	2,3, 5	Adhesion layers for ALD nucleation in the form of DNA molecules that wrap CNTs will be used. ALD after the DNA rinse will be done in order to prepare high-index thin layers. Nanomaterials such as SiO_2 or dielectric 2D materials to be directly deposited via biofabrication will be analysed.
Limitation in sorting (Likelihood L; Severity L)	4,5	If the fraction of metallic CNTs will be too high, electrical shortcuts approaches will be used to remove the conductive CNTs from the array.
Limitation in gaining sufficient control over the doping level of the CNTs (H; M)	4	Intrinsic semiconducting SWCNTs can be used as channel, which is contacted either by N-type (Sc or Y) or P-type (Pd) electrodes.
Stray charges, interactions, local variations between different close CNTs (M; H)	2,5	CNTs are sensitive to any charge in their vicinity, FETs and logics designs comprising Gate All Around will be investigated to address this challenge.
Limit in CNTs size for crossbar RRAMs fabrication ((Likelihood M; Severity L)	2-5	Crossbar RRAMs is one of the potential designs for non-volatile memories. Alternative designs using modified/functionalized CNTs (for example with molecular magnets to create local magnetic fields along the CNT length) can be considered as demonstrated in literature for planar designs [10.1002/adfm.202107224; 10.1038/ncomms1415]
Limit in upscaling – large scale fabrication (Likelihood H; Severity H)	2,3, 5	There are several established protocols to tackle this problem [10.1038/nnano.2009.220, 10.1021/nn506014s, 10.1126/science.abd6179] which the PI at FRI has been evaluating with all the required facilities available in house.
Limits in tip-to-sample approach in 3D SPM	6	Lateral scan system will be optimized to allow the probe tips to move toward the biofabricated device until a tunnel current is detected avoiding collisions.

Table 3.2f: **Summary of staff effort**

	WP1	WP2	WP3	WP4	WP5	WP6	WP7	Total Person/Months
1. IIT	**9**	18	2	2	**42**	14	**9**	96
2. ULEI	1.5	2	**36**	3	16	5	1	64.5
3. FRI*	1.5	3	**36**	3	22.5	5	1	72
4. UHAM	1.5	1	1	1	5	**45**	1	55.5
5. UANT	1.5	1	1	**35**	1	2	1	42.5
6. KIT	1.5	1	1	**34**	1	2	1	41.5
7. KER	1.5	**36**	2	1	8	15	1	64.5
8. ICN2	1.5	2	1	3	2	**20**	1	30.5
9. CNAT	**5**	2	1	1	1	1	**20**	31
Total Person/Months	24.5	66	81	83	98.5	109	36	498

Table 3.2h: '**Purchase costs**' items (travel and subsistence, equipment and other goods, works and services)*
For the participants with 'Purchase costs' above the 15% of the personnel costs, all the costs are here reported.

1 IIT	Cost (€)	Justification
Travel	17.200	3 Scientific conferences (EU/int) for 2 persons + Project meetings
Equipment	9.600	Workstation
Other goods and services	88.600	Consumables for clean room (e.g., Pd, Sc, Y for ALD) and characterization facility (30k€); Software license renewal (multiphysics software) (12k€); Costs for dissemination and communication activities (17k€); IP & Exploitation (9k).
Total	115.400	

2 ULEI	Cost (€)	Justification
Travel	8.000	Scientific conferences and project meetings for 2 persons.
Other goods and services	55.000	DNA staple strands, gold nanoparticles, Chemical lab supplies basic chemicals, water filters, spin filters and columns, gel-electrophoresis materials, TEM grids, TEM maintenance (40k€) ; Open Access to publications (APCs) (10k€).
Total	63.000	

3 FRI*	Cost (€)	Justification
*To be noted that FRI is an affiliated partner (from Switzerland), hence no 'Purchase costs' needs to be justified.		

4 UHAM	Cost (€)	Justification
Travel	8.000	Scientific conferences and project meetings for 2 persons.
Equipment	75.000	Vector network analyser (for time-resolved characterization)
Other goods and services	55.000	Consumables: ultra-sharp tips, ultrahigh vacuum components, filaments, sample holders, gases, chemicals, etc.
Total	138.000	

5 UANT	Cost (€)	Justification
Travel	8.000	Scientific conferences and project meetings for 3 persons.
Other goods and services	50.000	Chemicals including raw CNTs, solvents, electron-donor and electron-acceptor molecules, surfactants and density gradient media, chemical labware, laser systems maintenance, cryogenics. Open access costs for data and publications.
Total	58.000	

6 KIT	Cost (€)	Justification
Travel	8.000	Scientific conferences and project meetings for 2 persons.
Other goods and services	50.000	Raw CNT material, density gradient medium for rate zonal centrifugation, sonicator heads to prepare CNT dispersions, PEG and dextran, solvents, alkane filler molecules, surfactants, AFM tips, TEM grids, cuvettes for spectroscopic analysis, etc.
Total	58.000	

7 KER	Cost (€)	Justification
'Purchase costs' for KER does not exceed 15% of the personnel costs, does not need to be reported		

8 ICN2	Cost (€)	Justification
Travel	8.000	Scientific conferences and project meetings for 3 persons.
Other goods and services	43.000	5k€ Software licenses; 6k€ open access publication charges; audit charges (€6k), (€2k) T-Sensor; Standard optical elements, sensors, x-y stage
Total	51.000	

9 CNAT	Cost (€)	Justification
'Purchase costs' for CNAT does not exceed 15% of the personnel costs, does not need to be reported		

Table 3.2i: 'Other costs categories" items

8 ICN2	Cost €	Justification
Internally invoiced goods & services	30.000	Clean room (€15k); AFM facility (€1k); X-ray services (€7k);TEM facility (€7k)

Table 3.2j: 'In-kind contributions' provided by third parties

Third party name	Category	Cost (€)	Justification
ICREA, Institucio Catalana de Recerca i Estudis Avancats	Seconded personnel	0	ICREA provides resources (salary of Prof. Sotomayor Torres) free of charge to ICN2 as a 3rd party giving in-kind contributions to the action (Article 9.2 Grant Agreement). The total cost will declared by ICN2 under Article 6 and will be included in Annex 2 as part of the costs of ICN2.

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