Horizon 2020

Call: H2020-FTIPilot-2016
(Fast Track to Innovation Pilot)

Topic: FTIPilot-01-2016

Type of action: IA
(Innovation action)

Proposal number: 760758

Proposal acronym: Hercules

Deadline Id: H2020-FTIPilot-2016-1

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How to fill in the forms

The administrative forms must be filled in for each proposal using the templates available in the submission system. Some data fields in the administrative forms are pre-filled based on the previous steps in the submission wizard.

Proposal ID **760758** *Acronym* **Hercules**

1 - General information

Topic	FTIPilot-01-2016
Call Identifier	H2020-FTIPilot-2016
Type of Action	IA
Deadline Id	H2020-FTIPilot-2016-1

Acronym	Hercules
Proposal title*	Ultra-strong, ultra-light fractal structures for aerospace and defence

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

Duration in months	*36*
Fixed keyword	*Advanced materials*
Free keywords	*Ultra-strong, ultra-light, fractal, structures, scaling law, engineering*

Abstract

The search for strong but light structures goes hand-in-hand with the history of civil engineering, human exploration and increased mobility. Strong, light structures are essential to tall towers, wide bridges, fast ships, efficient cars, commercial air travel, manned and unmanned air defence, launching satellites, exploring space and visiting Mars. With the persistent growth in air traffic, the rise in unmanned air vehicles, and renewed interest in space, the demand for stronger, lighter structures is greater than ever. Materials science has produced extremely light materials, but manufacturing them with sufficient size or strength looks impractical. We need a radical new approach, and one which integrates the design process with the method of manufacture.

In this proposal, we will manufacture, test and bring to market ultra-strong, ultra-light structures for aerospace and defence. By combining our previous research on fractal structures with recent advances in 3D printing and increased demand for efficient structures, we will bring our current product to successful commercialization and generate profit.

Remaining characters 874

Has this proposal (or a very similar one) been submitted in the past 2 years in response to a call for proposals under the 7th Framework Programme, Horizon 2020 or any other EU programme(s)? ● Yes ○ No

Please give the proposal reference or contract number.
757073

Proposal ID **760758**	Acronym **Hercules**

Declarations

1) The coordinator declares to have the explicit consent of all applicants on their participation and on the content of this proposal.	☒
2) The information contained in this proposal is correct and complete.	☒
3) This proposal complies with ethical principles (including the highest standards of research integrity — as set out, for instance, in the European Code of Conduct for Research Integrity — and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct).	☒

4) The coordinator confirms:

- to have carried out the self-check of the financial capacity of the organisation on http://ec.europa.eu/research/participants/portal/desktop/en/organisations/lfv.html or to be covered by a financial viability check in an EU project for the last closed financial year. Where the result was "weak" or "insufficient", the coordinator confirms being aware of the measures that may be imposed in accordance with the H2020 Grants Manual (Chapter on Financial capacity check); or	◉
- is exempt from the financial capacity check being a public body including international organisations, higher or secondary education establishment or a legal entity, whose viability is guaranteed by a Member State or associated country, as defined in the H2020 Grants Manual (Chapter on Financial capacity check); or	○
- as sole participant in the proposal is exempt from the financial capacity check.	○

5) The coordinator hereby declares that each applicant has confirmed:

- they are fully eligible in accordance with the criteria set out in the specific call for proposals; and	☒
- they have the financial and operational capacity to carry out the proposed action.	☒
The coordinator is only responsible for the correctness of the information relating to his/her own organisation. Each applicant remains responsible for the correctness of the information related to him/her and declared above. Where the proposal to be retained for EU funding, the coordinator and each beneficiary applicant will be required to present a formal declaration in this respect.	

According to Article 131 of the Financial Regulation of 25 October 2012 on the financial rules applicable to the general budget of the Union (Official Journal L 298 of 26.10.2012, p. 1) and Article 145 of its Rules of Application (Official Journal L 362, 31.12.2012, p.1) applicants found guilty of misrepresentation may be subject to administrative and financial penalties under certain conditions.

Personal data protection

Your reply to the grant application will involve the recording and processing of personal data (such as your name, address and CV), which will be processed pursuant to Regulation (EC) No 45/2001 on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data. Unless indicated otherwise, your replies to the questions in this form and any personal data requested are required to assess your grant application in accordance with the specifications of the call for proposals and will be processed solely for that purpose. Details concerning the processing of your personal data are available on the privacy statement. Applicants may lodge a complaint about the processing of their personal data with the European Data Protection Supervisor at any time.

Your personal data may be registered in the Early Warning System (EWS) only or both in the EWS and Central Exclusion Database (CED) by the Accounting Officer of the Commission, should you be in one of the situations mentioned in:
-the Commission Decision 2008/969 of 16.12.2008 on the Early Warning System (for more information see the Privacy Statement), or
-the Commission Regulation 2008/1302 of 17.12.2008 on the Central Exclusion Database (for more information see the Privacy Statement) .

Proposal ID **760758** *Acronym* **Hercules**

List of participants

#	Participant Legal Name	Country
1	StructX Ltd	United Kingdom
2	LONDON CENTRE FOR MATHEMATICAL SCIENCES LBG	United Kingdom
3	CONSIGLIO NAZIONALE DELLE RICERCHE	Italy
4	FUNDACION PRODINTEC	Spain
5	RAMEM SA	Spain

Proposal ID **760758** *Acronym* **Hercules** *Short name* **Hercules**

2 - Administrative data of participating organisations

PIC	***Legal name***
917026458	*StructX Ltd*

Short name: Hercules

Address of the organisation

Street 35a South Street, London

Town London

Postcode W1K 2XF

Country United Kingdom

Webpage

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....no

Non-profit ....no

International organisation ....no

International organisation of European interest ......no

Secondary or Higher education establishment ....no

Research organisation ....no

Legal person .... yes

Industry (private for profit)............. yes

Please note that your industry status is calculated automatically from the data entered in the research and innovation related data section on the beneficiary register. If the data entered in the beneficiary register are incorrect or unknown, EC services might not be able to decide on the eligibility of your proposal.

Enterprise Data

SME self-declared status.................................2016 - yes

SME self-assesment ....2016 - yes

SME validation sme.. unknown

Based on the above details of the Beneficiary Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

NACE Code: -

Department(s) carrying out the proposed work

Department 1

Department name: n/a

☐ not applicable

☒ Same as organisation address

Street: 35a South Street, London

Town: London

Postcode: W1K 2XF

Country: United Kingdom

Dependencies with other proposal participants

Character of dependence	***Participant***	

Proposal ID **760758**	*Acronym* **Hercules**	*Short name* **Hercules**

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Ms

Sex: ◯ Male ◉ Female

First name: **Adrienn**

Last name: **Avrai**

E-Mail: **adrienn@structx.co.uk**

Position in org.: Administrator

Department: Administration office

☐ Same as organisation

☒ Same as organisation address

Street: 35a South Street, London

Town: London

Post code: W1K 2XF

Country: United Kingdom

Website:

Phone 1: +442034174945

Phone 2: +xxx xxxxxxxxx

Fax: +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Antonia	TINGEY	at@lims.ac.uk	+442034174945

Proposal ID **760758**	Acronym **Hercules**	Short name **LIMS**

PIC	***Legal name***
987729952	*LONDON CENTRE FOR MATHEMATICAL SCIENCES LBG*

Short name: LIMS

Address of the organisation

Street SOUTH STREET 35A MAYFAIR

Town LONDON

Postcode W1K 2XF

Country United Kingdom

Webpage www.london-institute.org

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....no

Non-profit ....yes

International organisation ....no

International organisation of European interest ......no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person .... yes

Industry (private for profit)............. no

Please note that your industry status is calculated automatically from the data entered in the research and innovation related data section on the beneficiary register. If the data entered in the beneficiary register are incorrect or unknown, EC services might not be able to decide on the eligibility of your proposal.

Enterprise Data

SME self-declared status.................................2013 - no

SME self-assesment .... unknown

SME validation sme....................................... unknown

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

NACE Code: 721 - Research and experimental development on natural sciences and engineering

Department(s) carrying out the proposed work

Department 1

Department name: n/a

☐ not applicable

☒ Same as organisation address

Street	SOUTH STREET 35A MAYFAIR
Town	LONDON
Postcode	W1K 2XF
Country	United Kingdom

Dependencies with other proposal participants

Character of dependence	***Participant***	

Proposal ID **760758** *Acronym* **Hercules** *Short name* **LIMS**

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Ms

Sex: ◯ Male ◉ Female

First name: **Antonia** Last name: **Tingey**

E-Mail: **antonia@london-institute.org**

Position in org.: Grants Officer

Department: n/a ☐ Same as organisation

☒ Same as organisation address

Street: SOUTH STREET 35A MAYFAIR

Town: LONDON Post code: W1K 2XF

Country: United Kingdom

Website: www.lims.ac.uk

Phone 1: +442034174945 Phone 2: *+xxx xxxxxxxxx* Fax: *+xxx xxxxxxxxx*

Proposal ID **760758** *Acronym* **Hercules** *Short name* **CNR**

PIC	***Legal name***
999979500	*CONSIGLIO NAZIONALE DELLE RICERCHE*

Short name: CNR

Address of the organisation

Street PIAZZALE ALDO MORO 7

Town ROMA

Postcode 00185

Country Italy

Webpage www.cnr.it

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ......no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person .... yes

Industry (private for profit)............. no

Please note that your industry status is calculated automatically from the data entered in the research and innovation related data section on the beneficiary register. If the data entered in the beneficiary register are incorrect or unknown, EC services might not be able to decide on the eligibility of your proposal.

Enterprise Data

SME self-declared status.................................2015 - no

SME self-assesment .... unknown

SME validation sme.......................................2007 - no

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

NACE Code: 721 - Research and experimental development on natural sciences and engineering

Department(s) carrying out the proposed work

Department 1

Department name	Instituto dei Sistemi Complessi	☐ not applicable
	☐ Same as organisation address	
Street	Via dei Taurini 19	
Town	Rome	
Postcode	00185	
Country	Italy	

Dependencies with other proposal participants

Character of dependence	***Participant***	

Proposal ID **760758** Acronym **Hercules** Short name **CNR**

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (•) Male ( ) Female

First name: **Andrea** Last name: **Gabrielli**

E-Mail: **andrea.gabrielli@roma1.infn.it**

Position in org.: Permanent Research Position

Department: Dipartimento di Fisica ☐ Same as organisation

☐ Same as organisation address

Street: Piazzale Aldo Moro 5

Town: Rome Post code: 00185

Country: Italy

Website: www.sapienza.isc.cnr.it/your-details/userprofile/andreag.html

Phone 1: +390649913481 Phone 2: +xxx xxxxxxxxx Fax: +xxx xxxxxxxxx

Other contact persons

First Name	Last Name	E-mail	Phone
Antonio	Scala	antonio@london-institute.org	

PIC	***Legal name***
997171738	*FUNDACION PRODINTEC*

Short name: FUNDACION PRODINTEC

Address of the organisation

Street Avenida Jardin Botanico - Parque Cientifico y Te

Town Gijon

Postcode 33203

Country Spain

Webpage www.prodintec.com

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....no

Non-profit ....yes

International organisation ....no

International organisation of European interest ......no

Secondary or Higher education establishment ....no

Research organisation ....yes

Legal person .... yes

Industry (private for profit)............. no

Please note that your industry status is calculated automatically from the data entered in the research and innovation related data section on the beneficiary register. If the data entered in the beneficiary register are incorrect or unknown, EC services might not be able to decide on the eligibility of your proposal.

Enterprise Data

SME self-declared status.................................2012 - no

SME self-assesment .... unknown

SME validation sme.......................................2012 - no

Based on the above details of the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

NACE Code: DJ - Manufact. (basic metals, metal products)

Proposal ID **760758**	Acronym **Hercules**	Short name **FUNDACION PRODINTEC**

Department(s) carrying out the proposed work

Department 1

Department name: n/a

☐ not applicable

☒ Same as organisation address

Street: Avenida Jardin Botanico - Parque Cientif

Town: Gijon

Postcode: 33203

Country: Spain

Dependencies with other proposal participants

Character of dependence	***Participant***	

Proposal ID **760758**	Acronym **Hercules**	Short name **FUNDACION PRODINTEC**

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: (•) Male ( ) Female

First name: **David**

Last name: **Gonzalez Fernandez**

E-Mail: **dgf@prodintec.com**

Position in org.: Director of Advanced Manufacturing

Department: n/a

☐ Same as organisation

☒ Same as organisation address

Street: Avenida Jardin Botanico - Parque Cientifico y Tecnologico Zona In

Town: Gijon

Post code: 33203

Country: Spain

Website: www.prodintec.es

Phone 1: +34984390060

Phone 2: +xxx xxxxxxxxx

Fax: +xxx xxxxxxxxx

Other contact persons

First Name	*Last Name*	*E-mail*	*Phone*
Juan Carlos	Piquero Camblor	jpg@prodintec.com	+34655559455

Proposal ID **760758** *Acronym* **Hercules** *Short name* **RAMEM**

PIC	***Legal name***
998869529	*RAMEM SA*

Short name: RAMEM

Address of the organisation

Street CALLE SAMBARA 33

Town MADRID

Postcode 28033

Country Spain

Webpage www.ramem.com

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....no

Non-profit ....no

International organisation ....no

International organisation of European interest ......no

Secondary or Higher education establishment ....no

Research organisation ....no

Legal person .... yes

Industry (private for profit)............. yes

Please note that your industry status is calculated automatically from the data entered in the research and innovation related data section on the beneficiary register. If the data entered in the beneficiary register are incorrect or unknown, EC services might not be able to decide on the eligibility of your proposal.

Enterprise Data

SME self-declared status.................................1985 - yes

SME self-assesment ....2014 - yes

SME validation sme.......................................2007 - yes

Based on the above details of the Beneficiary Registry the organisation is an SME (small- and medium-sized enterprise) for the call.

NACE Code: 93 - Sports activities and amusement and recreation activities

Department(s) carrying out the proposed work

Department 1

Department name: R&D Department ☐ not applicable

☐ Same as organisation address

Street: C/Verano, 9 Torrejon de Ardoz

Town: Madrid

Postcode: 28850

Country: Spain

Dependencies with other proposal participants

Character of dependence	***Participant***	

Proposal ID **760758** *Acronym* **Hercules** *Short name* **RAMEM**

Person in charge of the proposal

The name and e-mail of contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and basic contact details of contact persons, please go back to Step 4 of the submission wizard and save the changes.

Title: Dr.

Sex: ○ Male ◉ Female

First name: **Silvia**

Last name: **Vidal Lopez**

E-Mail: **slopez@ramem.com**

Position in org.: R&D Manager

Department: R&D Department

☐ Same as organisation

☐ Same as organisation address

Street: C/Verano, 9 Torrejon de Ardoz

Town: Madrid

Post code: 28850

Country: Spain

Website: www.ramem.com

Phone 1: +34914044575

Phone 2: +xxx xxxxxxxxx

Fax: +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
E	Ramiro	e.ramior@ramem.com	+34914044575

Proposal ID **760758** *Acronym* **Hercules**

3 - Budget for the proposal

No	Participant	Country	Industry	(A) Direct personnel costs/€	(B) Other direct costs/€	(C) Direct costs of sub-contracting/€	(D) Direct costs of providing financial support to third parties/€	(E) Costs of inkind contributions not used on the beneficiary's premises/€	(F) Indirect Costs / € (=0.25(A+B-E))	(G) Special unit costs covering direct & indirect costs / €	(H) Total estimated eligible costs / € (=A+B+C+D+F+G) BENEFICIARY	(I) Reimburse-ment rate (%) BENEFICIARY	(J) Max.EU Contribution / € (=H*I) BENEFICIARY	(K) Costs of third parties linked to participant THIRD PARTIES	(L) Max.EU Contribution / € THIRD PARTIES	(M) Total Costs for BENEFICIARY & THIRD PARTIES (=H+K)	(N) Max.EU Contribution / € BENEFICIARY & THIRD PARTIES (=J+L)	(O) Requested EU Contribution / € BENEFICIARY & THIRD PARTIES
1	Hercules	UK	Y	1184000	176000	0	0	0	340000,00	0	1700000,00	70	1190000,00	0	0	1700000,00	1190000,00	1190000,00
2	Lims	UK	N	450000	67500	0	0	0	129375,00	0	646875,00	100	646875,00	0	0	646875,00	646875,00	646875,00
3	Cnr	IT	N	300000	45000	0	0	0	86250,00	0	431250,00	100	431250,00	0	0	431250,00	431250,00	431250,00
4	Fundacion Prodintec	ES	N	180000	20000	0	0	0	50000,00	0	250000,00	100	250000,00	0	0	250000,00	250000,00	250000,00
5	Ramem	ES	Y	360000	40000	0	0	0	100000,00	0	500000,00	70	350000,00	0	0	500000,00	350000,00	350000,00
	Total			2474000	348500	0	0	0	705625,00	0	3528125,00		2868125,00	0,00	0,00	3528125,00	2868125,00	2868125,00

Proposal ID **760758**	Acronym **Hercules**

4 - Ethics issues table

1. HUMAN EMBRYOS/FOETUSES		Page
Does your research involve Human Embryonic Stem Cells (hESCs)?	◯ Yes ◉ No	
Does your research involve the use of human embryos?	◯ Yes ◉ No	
Does your research involve the use of human foetal tissues / cells?	◯ Yes ◉ No	
2. HUMANS		**Page**
Does your research involve human participants?	◯ Yes ◉ No	
Does your research involve physical interventions on the study participants?	◯ Yes ◉ No	
3. HUMAN CELLS / TISSUES		**Page**
Does your research involve human cells or tissues (other than from Human Embryos/ Foetuses, i.e. section 1)?	◯ Yes ◉ No	
4. PERSONAL DATA		**Page**
Does your research involve personal data collection and/or processing?	◯ Yes ◉ No	
Does your research involve further processing of previously collected personal data (secondary use)?	◯ Yes ◉ No	
5. ANIMALS		**Page**
Does your research involve animals?	◯ Yes ◉ No	
6. THIRD COUNTRIES		**Page**
In case non-EU countries are involved, do the research related activities undertaken in these countries raise potential ethics issues?	◯ Yes ◉ No	
Do you plan 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	
Do you plan to import any material - including personal data - from non-EU countries into the EU? *For data imports, please fill in also section 4.* *For imports concerning human cells or tissues, fill in also section 3.*	◯ Yes ◉ No	
Do you plan to export any material - including personal data - from the EU to non-EU countries? *For data exports, please fill in also section 4.* *For exports concerning human cells or tissues, fill in also section 3.*	◯ Yes ◉ No	

Proposal ID **760758** *Acronym* **Hercules**

If your research involves low and/or lower middle income countries, are benefits-sharing actions planned?	○Yes ◉No	
Could the situation in the country put the individuals taking part in the research at risk?	○Yes ◉No	
7. ENVIRONMENT & HEALTH and SAFETY		Page
Does your research involve the use of elements that may cause harm to the environment, to animals or plants? *For research involving animal experiments, please fill in also section 5.*	○Yes ◉No	
Does your research deal with endangered fauna and/or flora and/or protected areas?	○Yes ◉No	
Does your research involve the use of elements that may cause harm to humans, including research staff? *For research involving human participants, please fill in also section 2.*	○Yes ◉No	
8. DUAL USE		Page
Does your research have the potential for military applications?	○Yes ◉No	
9. MISUSE		Page
Does your research have the potential for malevolent/criminal/terrorist abuse?	○Yes ◉No	
10. OTHER ETHICS ISSUES		Page
Are there any other ethics issues that should be taken into consideration? Please specify	○Yes ◉No	

I confirm that I have taken into account all ethics issues described above and that, if any ethics issues apply, I will complete the ethics self-assessment and attach the required documents. ☒

How to Complete your Ethics Self-Assessment

Proposal ID **760758** *Acronym* **Hercules**

5 - Call specific questions

Eligibility of the proposal

Number of participants	5
Number of industry (private for profit) participants	2
% of budget (total estimated eligible costs) of industry participants	62%

Taking into account the information above, please indicate which of the following minimum conditions your proposal meets. You must be able to indicate at least one of the three options below:

At least 60 % of the budget of the proposal will be allocated to consortium partners from industry, i.e. private-for-profit entities.	☒
My consortium consists of 3 or 4 partners, and at least 2 of them are private-for-profit entities (industry participants).	☒
My consortium consists of 5 partners, and at least 3 of them are private-for-profit entities (industry participants).	☐

If your proposal meets none of three above criteria, your proposal will be found ineligible for support under the Fast Track to Innovation Pilot. Please note that your industry status is calculated automatically from the data entered in the research and innovation related data section on the beneficiary register. If the data entered in the beneficiary register are incorrect or unknown, EC services might not be able to decide on the eligibility of your proposal. In addition, please note that only applications involving entities all of whom are established in the EU Member States or countries associated to Horizon 2020 are eligible for the call, as defined in Article 9 of the Horizon 2020Rules for Participation and as determined in the Horizon 2020 Work programme section on the Fast Track to Innovation Pilot.

Open Research Data Pilot in Horizon 2020

If selected, all applicants have the possibility to participate in the Pilot on Open Research Data in Horizon 2020[1], which aims to improve and maximise access to and re-use of research data generated by actions. Participating in the Pilot does not necessarily mean opening up all research data. Actions participating in the Pilot will be invited to formulate a Data Management Plan in which they will determine and explain which of the research data they generate will be made open.

We wish to participate in the Pilot on Open Research Data in Horizon 2020 on a voluntary basis	○ Yes	◉ No

Participation in this Pilot does not constitute part of the evaluation process. Proposals will not be evaluated favourably because they are part of the Pilot and will not be penalised for not participating.

[1] *According to article 43.2 of Regulation (EU) No 1290/2013 of the European Parliament and of the Council, of 11 December 2013, laying down the rules for participation and dissemination in "Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)" and repealing Regulation (EC) No 1906/2006.*

Data management activities

The use of a Data Management Plan (DMP) is required for projects participating in the Open Research Data Pilot in Horizon 2020, in the form of a deliverable in the first 6 months of the project.

All other projects may deliver a DMP on a voluntary basis, if relevant for their research.

Are data management activities relevant for your proposed project?	○ Yes	● No

Ultra-strong, ultra-light fractal structures for aerospace and defence
Short title: Hercules

			First-time industry applicant
1 (Coordinator)	StructX Ltd	UK	Y (registered Sep 2016)
2	Ramem SA	Spain	N
3	CNR	Italy	n/a
4	Prodintec	Spain	n/a
5	London Institute	UK	n/a

Table of Contents

1 Excellence

1.1 Objectives

1.1.a Problem to overcome and our solution

The search for strong but light structures goes hand-in-hand with the history of civil engineering, human exploration and increased mobility. Strong, light structures are essential to tall towers, wide bridges, fast ships, efficient cars, commercial air travel, manned and unmanned air defence, launching satellites, exploring space and visiting Mars. With the persistent growth in air traffic, the rise in unmanned air vehicles, and renewed interest in space, the demand for stronger, lighter structures is greater than ever. Materials science has produced extremely light materials, but manufacturing them with sufficient size or strength looks impractical. We need a radical new approach, and one which integrates the design process with the method of manufacture.

In this proposal, we will manufacture, test and bring to market ultra-strong, ultra-light structures for aerospace and defence. By combining our previous research on fractal structures with recent advances in 3D printing and increased demand for efficient structures, we will bring our current product to successful commercialization and generate profit.

What we have done so far

- Discovered over the last nine years that fractal structures can be extremely strong and light.
- Identified four basic fractal structure types: struts, plates, shells and space-filling (Fig. 1.1).
- Mathematically and computationally modelled our structures and showed them to be stable.
- Manufactured our strut using 3D printing in polymer and tested it for strength.
- Won a €162,000 contract with the UK Ministry of Defence to make, test and deliver 12 structures.

What we will do in this FTI project

- Manufacture and our full range of structures in polymer in and metal.
- Leverage our Ministry of Defence contract to attract other EU and US defence contracts.
- Create a website and brochure to market our product range to aerospace and defense.
- Sell structure designs for manufacture by the customer, customised to their particular needs.
- Create an online repository of standard structures, available for download for a fee.

Our project, Hercules, is at the centre of a perfect storm of concept, feasibility and demand.

(i) *We discovered that fractal structures can be ultra-efficient.*
In a series of research papers over the last nine years (Section 4.1.d), we discovered that certain self-similar, hierarchical (fractal) structures have new strength-to-mass scaling relations. This means that fractal structures can offer almost unbounded gains in mechanical efficiency, limited by the precision of the manufacturing process.

(ii) *Technological advances make 3D printing feasible.*
Fractal structures are hard to manufacture by conventional methods. But recent advances in the reliability and resolution of 3D printing (also known as additive manufacturing) mean that we can finally use it to make our structures, at an affordable cost.

(iii) *Demand for strong, light structures is accelerating.*

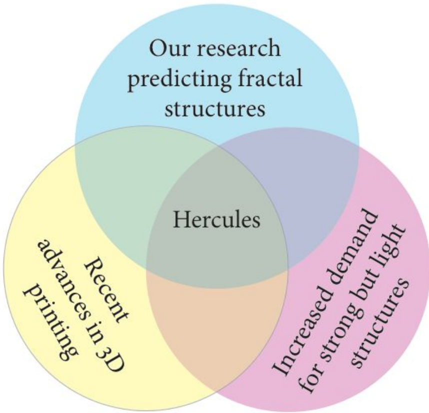


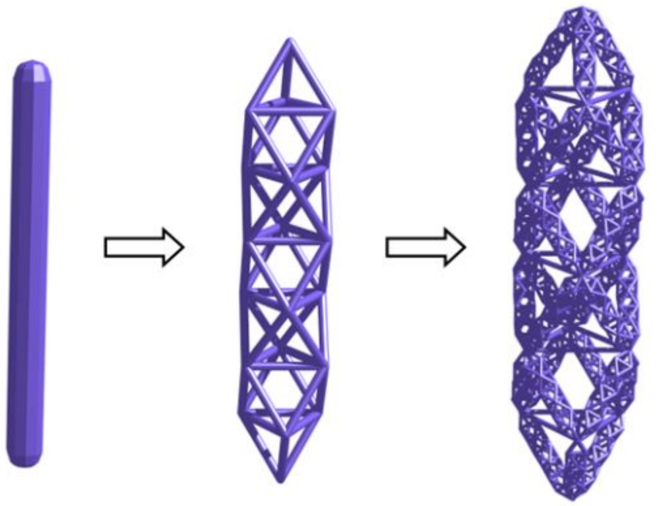
Figure 1.1. Our project lies at the intersection of our existing research results, recent advances in 3D printing, and increased demand for strong but light structures. The result is an opportunity to harness untapped potential in the manufacturing industry to make more efficient structures and generate profit.

Increased mobility demands, the rise of drones in commerce and defence, and a renewed interest in space mean that the market for highly efficient structures is greater than ever.

Our fractal structures

Through a series of discoveries over the last nine years, we have developed, optimised and (for some) tested the following basic structures types. Each may be customised if need be to satisfy a users particular design needs.

Strut	Linear support to withstand compression
Plate	Flat planar support to withstand pressure
Shell	Curved planar support to withstand pressure
Filling	Space-filling support to withstand distributed load
Truss	Branching column to withstand distributed load on top, compression on bottom



Truss structure

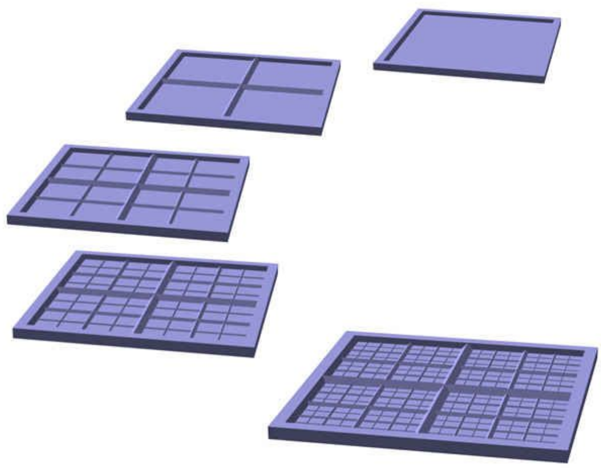
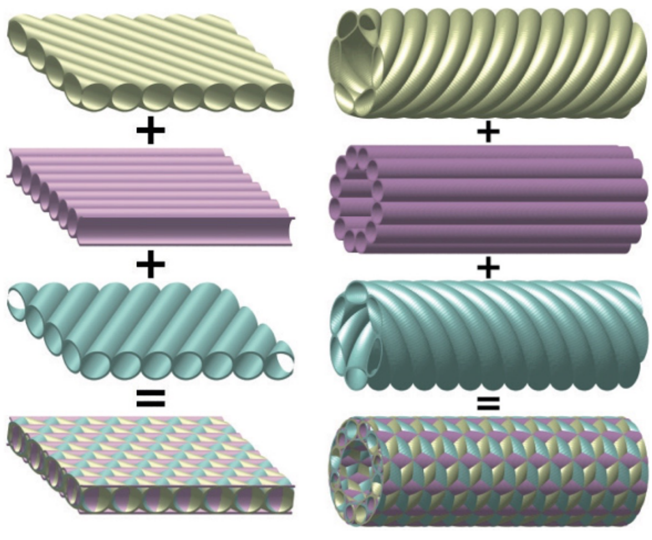
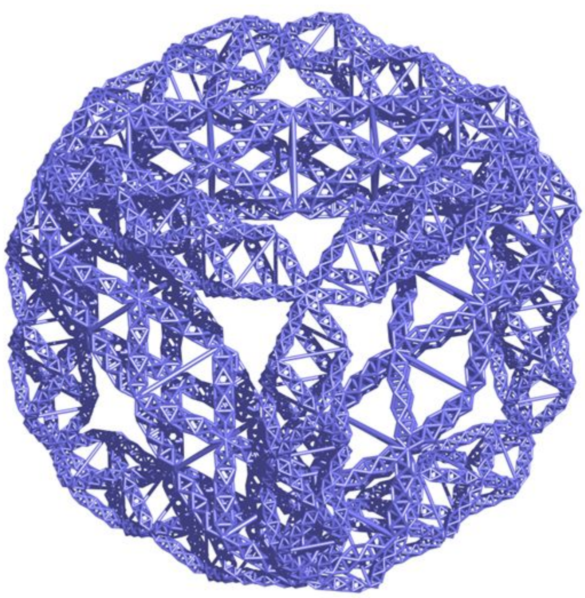


Plate structure



Shell structure



Space-filling structure (example of just one unit cell)

Figure 1.2. Our four ultra-strong, ultra-light fractal structures.

1.1.b EU-wide relevance

Demand for our strong, light structures is led by aerospace, and the leading technology for manufacturing them is 3D printing. These two sectors are not the only ones relevant to our product, but they are the biggest. Here we show that European aerospace is a well-established, dominant global force, and that Europe is leading the way in the explosive growth of 3D-printing technology.

Aerospace. Aerospace is one of Europe's strengths, accounting for one third of the world's aerospace business. Leading companies Airbus, Safran, Finmeccanica, Rolls Royce, BAE Systems, Thales, Zodiac and MTU Aero Engines have a combined value of €150bn. The European Commission report *Strategic Aerospace Review for the 21st Century (STAR 21)* concludes that "aerospace is vital to meeting Europe's objectives for economic growth, security and quality of life", and that "Europe must remain at the forefront of key technologies if it is to have an innovative and competitive aerospace industry".

3D printing. One of those key technologies is 3D printing, also known as additive manufacturing, and Europe is at the forefront. The map to the right shows the leading EU countries in terms of the number of industrial 3D-printer sales, which gives an indication of their commitment to the sector. Globally, Europe has half of the ten countries most-committed to 3D printing technology.

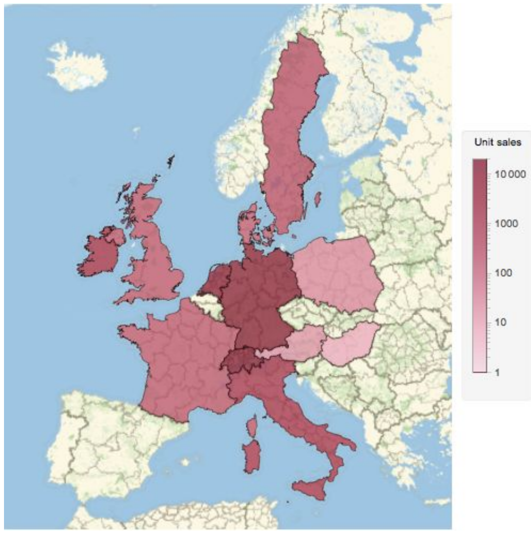


Figure 1.3. Industrial 3D-printing sales in 2015, by country. Source: *Wohlers Report 2016*.

1.2 Relation to the work programme

This proposal responds to "FTIPilot-01-2016: Fast Track to Innovation Pilot". We quote relevant parts of the call and explain how our project relates to it.

Work programme calls for	*How our product relates to it*
"Fast development, commercial take-up…of sustainable innovative solutions in enabling and industrial technologies"	This project will fast-forward the state-of-the-art for strong, light structures for aerospace, defence and the built environment. It combines previously published research from our consortium with recent advances in 3D printing and increased demand for strong but light structures. The technological feasibility and increased demand puts us in a strong position for creating profit.
"Time to initial market take-up no later than 3 years."	Our strut and shell structures will go to market during the first 18 months of this project, and during months 19–36, two of our three remaining structures types will go to market, depending on tests.
"Enhanced competitiveness and growth of business partners in the consortium, measured in terms of turnover and job creation."	Our structures cannot be made without the participation of the 3D-printing industry, and the 3D-printing industry must adopt next-generation structure concepts if they are to win the full support of the aerospace and defence industries. Working together, our two SMEs London Inst. and Ramen SA and manufacturer Prodintec will boost their competitiveness and create between them 12–15 new jobs during this 36-month project, and catalyse further growth beyond it.
"Increased industry participation, including SMEs, and more industry first-time applicants."	Two of our consortium partners are SMEs (which account for over 60% of the budget), one of which is a first-time applicant to H2020. A third, Spanish manufacturer Prodintec, is non-profit but an SME in spirit.

Four of our partners already work directly with the aerospace and defence industries, and FTI support will enable them to boost this.

“Leveraging more private investment into research and/or innovation.”

We have recently had €162,000 investment into our concept from the UK Ministry of Defence, and will seek further private investment from the defence and aerospace industries. Our UK partners have experience winning UK and US defence contracts, and our Spanish partners Airbus and Aciturri Aeronáutica contracts.

1.3 Concept and approach

1.3.a Concept

A fractal has the property that any part of it, when magnified, resembles the whole. Examples of this special kind of hierarchy include the snowflake-like Koch curve and the Mandelbrot set. Many physical processes exhibit fractal geometry, such as random walks, percolation and several chaotic systems. In terms of structure, certain types of sticky diffusion lead to fractal aggregates; but these are in no way optimized for mechanical performance.

Remarkably, biology employs fractal designs to achieve high efficiency: spongy bone for stiffness; ramified networks for gas exchange; and self-similar spiral shells for pressure resistance. But in the man-made world, the reverse is true: fractal designs are rarely used for mechanical efficiency. Transmission towers and the branching columns of Gaudi’s cathedral Sagrada Familia hint at fractal design principles; but the small number of hierarchical levels and the lack of quantitative understanding suggest these are heuristic.

physicsworld.com

Feature: Fractal structures

Towers of strength

Daniel Rayneau-Kirkhope, Yong Mao and Robert Farr describe how efficient fractal structures in the natural world are inspiring scientists to develop new materials

The Eiffel Tower was never intended to be a permanent feature of the Parisian landscape. Built for the 1889 World Fair, the plan was to leave the tower in its original location until 1909, when it would be dismantled piece by piece and reassembled elsewhere. However, with the tower still present in 1925, a fraudster called Victor Lustig spotted an opportunity. Posing as a government official, Lustig convinced six scrap-metal dealers that, as the maintenance costs of the tower had grown to outweigh all its benefits, it was due to be scrapped, and he invited them to bid for the job. An auction commenced, but as soon as the “successful” bidder had parted with cash, Lustig fled Paris for Vienna. A month later he returned to repeat the scam, thus becoming notorious as the man who fraudulently sold the Eiffel Tower for scrap metal – twice.

Almost a century after Lustig’s con, the Eiffel Tower still dominates the French capital’s skyline and is celebrated as one of the world’s most iconic structures. However, even if Lustig had been telling the truth, the scrap dealer might still have been disappointed. One of the tower’s most remarkable features is its sparing use of material: if all the iron in the 320 m-high Eiffel Tower were melted down to form a solid block with a base area equal to the tower’s, the block would stand only 6 cm tall. This surprising fact is a direct result of the tower’s architect, Gustave Eiffel, having designed it to be built from iron beams that are much smaller than the tower’s finished height. The smallest beams were used

Daniel Rayneau-Kirkhope is a Science Fellow at Aalto University, Finland. Yong Mao is a physicist at the University of Nottingham, UK. Robert Farr is a physicist at the London Institute for Mathematical Sciences, e-mail daniel.rayneau-kirkhope@aalto.fi

Figure 1.4. Our fractal structures were the subject of a feature article in *Physics World*.

True fractal designs offer mechanical efficiency because the advantage achieved at each generation can in principle be passed on to the next generation, and so on down to the smallest scale. In practice, of course, atoms exist, and different physical laws apply as components become very small. However over many length scales, fractal structures represent a bold shift in design philosophy capable of delivering enormous gains in efficiency. In a series of papers (partially listed in Section 4.1.d), we proved for the first time that fractal design principles exhibit remarkable new strength-to-mass scaling relations. These improved scaling laws can offer extraordinary advantage, especially for large structures or light loads. Some of our new fractal designs are shown in Fig. 1.2.

1.3.b Our product so far

Our product is the result of a nine-year journey to find ultra-strong, ultra-light structures. Only in the last few years has technology caught up with our predictions. Now that additive manufacture of our structures is feasible, we are developing and commercialising them.

Timeline of development and feasibility assessment to date

The following was done by members of our consortium:

	2007	Fractal plate and shell properties predicted in papers in P*hysical Review E*
	2008	Fractal strut and meta-material properties predicted in a paper in *Europhysics Letters*
	2011	Pressure resistance of fractal shells studied
	2012	Self assembly of Sierpinski gasket studied theoretically
	2012	Theory for fractal space-frames from hollow tubes published in *Physical Review Letters*
	2012	3D printing specialists at Nottingham University manufactures our first designs
	2013	Physics World feature article on fractal structures appears
	2013	Farr gives talk on “Fractal structures and architectural innovation” at London Institute
	2013	Subcontractor London Institute begins working on fractal structures
	2013	First summer intern arrives from Caltech, studies fractal truss (branching column)
	2014	Imperfections in flat fractal structures studied
	2015	Azhar Architecture meets with us, discusses applications in the built environment
May	2016	UK Ministry of Defence contracts us to build and test 12 prototypes (struts and shells)
Jul	2016	Recruitment of a specialist in continuum mechanics
Sep	2016	We negotiate with our subcontractor to manufacture further designs

We have conducted extensive strength, lightness and stability tests of our fractal structures

	2007	Strength and lightness of plate and shell calculated
	2008	Strength and lightness of strut and meta-material calculated
	2012	Elastic deformation of one fractal strut measured
	2013	Stability analysis of fractal truss (branching column; no new scaling law yet)
	2015	Truss mechanical advantage calculated (but not elastic deformation)
Oct	2016	Strut and shell structures made and measured to determine scaling properties

Positioning

Our technology readiness level for our different structure types is 6-7, for the following reasons:

Product prototype has been demonstrated in an operational environment.

Capability to produce a prototype system in a production relevant environment.

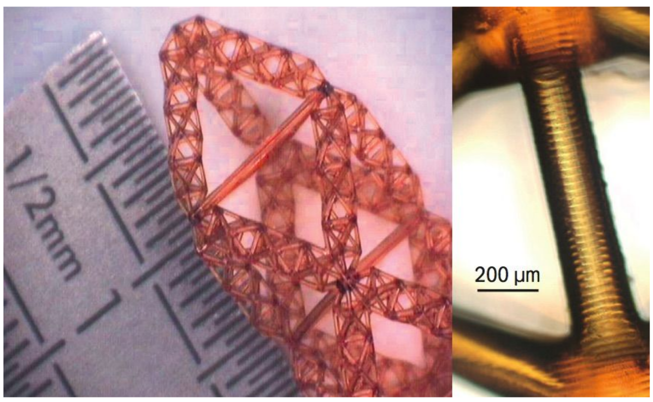


Figure 1.5 Example of our 3D-printed fractal truss. The inset shows the layered nature of the material, which is a consequence of the layer-by-layer printing process.

1.3.c Next steps for product development

Manufacture

We have previously used the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing to 3D print some of our structures. To successfully commercialise our product, we decided to step up our manufacturing partner. We considered over a dozen of the leading manufacturers in Europe and Israel, and entered detailed plans with four of them. On the strength of their technical ability in polymer and metal, and track record of providing end-use components to aerospace and defence companies, we chose Prodintec to manufacture our range of products, and Ramem SA to post-process, test and help market it (see below). Prodintec will manufacture our fractal struts, plates, shells, space-filling material in titanium alloy and other end-use materials.

Test and post-processing

Ramem SA will post-process the structures, including surface cleaning and smoothing, heat treatment for eliminating defects and fracture nucleation sites, and machining and testing for strength and tolerances demanded by our aerospace and defence users. Even for moderately complex structures, it is difficult to predict the different ways it might fail under high loads, whatever the method of manufacture. Our structures were chosen on the basis that we could solve for their failure modes. So far we have tested all our structures computationally, and our strut physically. In this project we will physically test our remaining three structure types to establish the failure loads and determine the failure modes. We will use full field digital video to capture the deformation history and elastic response. By comparing the failure loads and elastic response of our fractal structures to non-fractal alternatives, we will map out the parameter space where fractals are practically superior to conventional alternatives. This will be of use in determining the range of applications for commercialization. Once manufactured by 3D-printing, our structures will require a range of post-processing operations: surface smoothing, machining, strength treatment and quality control.

New designs

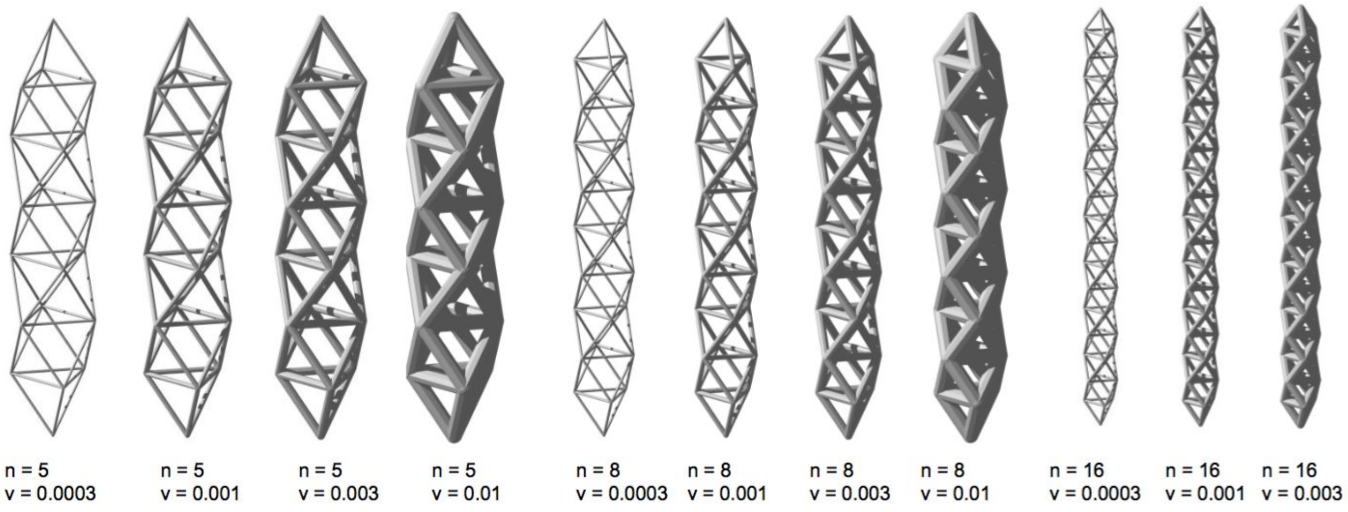
We will also work to extend our product range, by discovering new fractal structure types. The first step is to identify a self-similar, hierarchical structure with an improved strength-to-mass scaling relation; most fractal structures do not have this. The second step is to determine, from these, which designs are intrinsically stable. The trick to doing this latter step is proving that instabilities at one level of hierarchy do not propagate up to the next, higher level of hierarchy. Because our structures are self similar, once we have shown this “inductive step”, it applies to the whole object across all generations. A beneficial secondary outcome would be general design principles for fractal structures, which have so far proved elusive.

Design-manufacture integration

Optimal design takes into account the method of manufacture, and the ideal manufacturing technique is optimised to boost the performance of the design. This is especially for high-performance structures like ours that operate at the edge of what’s possible. During the first 12 months of our project, we will optimise the design of our structures for 3D printing. During the second 12 months, we will do the opposite: modify the method of manufacturing and post-processing to optimise the performance of our designs. The third and final 12 months will be spent iterating between these to, integrating the design and manufacture processes.

Industry-specific applications

As we continue to manufacture and test further designs, and expand the material range they are made from, we will clarify and formalize the force and pressure ranges and the applicable length scales for our range of five basic structure types. This will enable us to present more clearly the applications when marketing, discussed below. Specifically, the relevant parameter is the applied force divided by the elastic modulus of the material and the square of the system size. For small values of this non-dimensional loading parameter, fractal structures are superior to conventional ones.



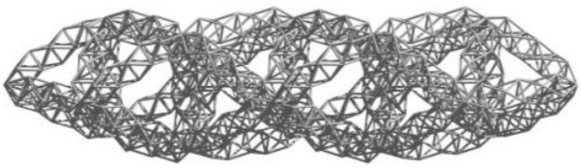


Figure 1.6. Top: Variations on our 1st-generation fractal strut, where n is the number of segments and v is the volume of material, or mass. Right: An example of our 2nd-generation fractal structure. We have used the EPSRC Centre for Innovative Manufacturing in Additive Manufacturing to 3D print these in nylon. In this FTI project, we are moving to commercialise them by making them in titanium alloy and other materials used by aerospace and defence. We will similarly manufacture and optimise our shell, plate and space-filling structures.

1.3.d Next steps for reaching the market

Value chain link 1: Physical prototypes

The completion of our first defence contract, which will occur in 2017, gives us a platform to attract further early users, such as defence agencies seeking innovative structural designs and large original equipment manufacturers (see Section 2.1.a). One of the advantages of working with defence contractors is that, once they perceive a promising solution, they often continue invest until it is market ready.

Value chain link 2: Custom designs

Users from the aerospace sector will typically have specific needs, and require a potentially customized design which they will then want to manufacture themselves. This link in our value chain will involve some manufacturing for demonstration purposes and then sales of customised designs rather than the physical prototypes above.

Value chain link 3: Design repository

We will develop a design repository in which users can download standardized structural components for a fee. This forms the third link in our value chain, and it requires the least customization, making the variable costs to our company per design download small. This is intended for our final users (see Section 2.a.a).

Retrain users design sense of what's possible

3D printing is an entirely new approach to design, and many of the constraints and drivers in traditional design (assembly or subtractive) do not apply. Many original equipment manufacturers, for instance, will have a limited outlook on the possibilities of innovative structural solutions. We will therefore need a strong, visual-focused marketing campaign, including both a website and product brochure, to communicate our designs and how they can be customized.

1.4 Ambition

1.4.a Strength of our product

At the heart of our product is a new scaling law for how much mass is needed to support a given force (below left) or pressure (below right). We illustrate this by analogy in the box below, and visually in Fig. 1.5 below that.

The breakthrough advantage of our fractal structures is an improved strength-to-mass scaling relation. To illustrate the gains from an improved scaling relation, here we consider an imaginary example in terms of the more familiar concept of volume. The amount of beer that an ordinary vessel can hold scales with its height to the power 3 (we assume the vessel shape stays roughly the same). Now imagine that we discovered a radically new type of vessel—call it a 'fressel'—with a different scaling relation: the amount of beer it can hold scales with its height to the power 1.5. Assume a 1 metre-tall barrel version of both the vessel and the fressel can hold a standard 150 litres. Then, by the two scaling laws, a 15 cm vessel holds ½ litre, whereas a 15 cm fressel holds 8.7 litres. A 1 cm vessel holds 0.15 ml, whereas a 1 cm fressel holds 150 ml. At a height of 1 mm, a fressel holds 32,000 times as much beer as an ordinary vessel (right). Thus we see that a fressel is a much superior container for small volumes. In a similar way, fractal structures are much superior for light loads or large structures.

Height	*Vessel volume*	*'Fressel' volume*
1 m	150 l	150 l
15 cm	0.500 l	8.700 l
1 cm	0.15 ml	150 ml
1 mm	0.15 μl	4700 μl

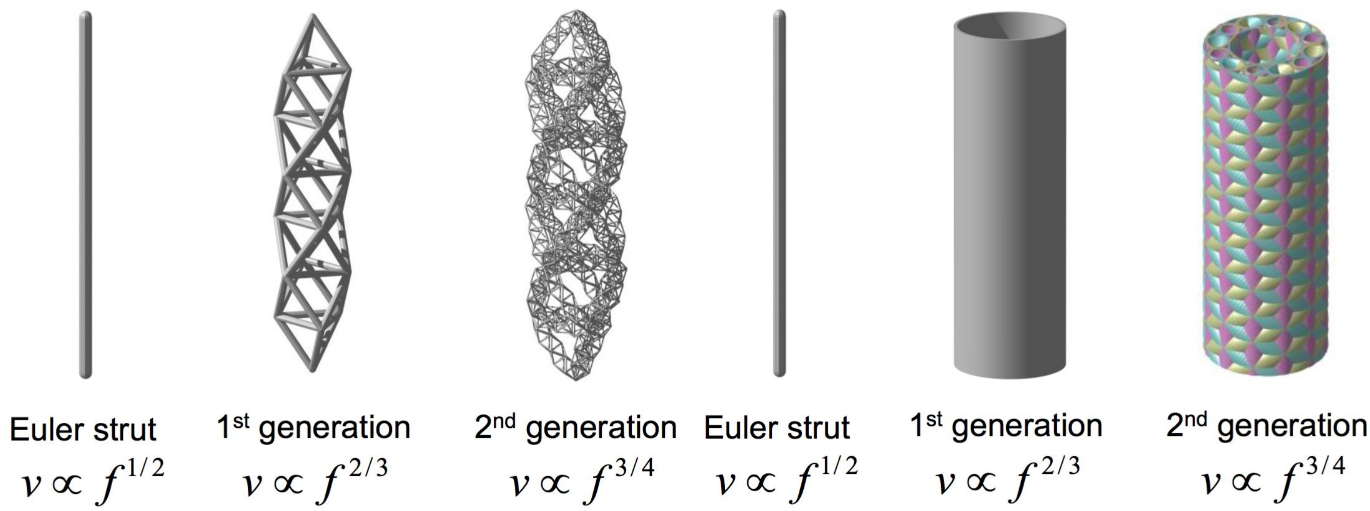


Figure 1.7. The volume of material in our structures is v, and the force or pressure they can withstand is f. For both our fractal strut (left) and fractal shell (right), the scaling relation gets better with each subsequent fractal generation. For instance, consider an Euler strut which is too strong for our needs. If we reduce the force by a factor of 10, we need 32% as much mass to withstand it. But for our 2nd generation fractal strut, we need 18% as much mass. If we reduce the force by a factor of 100, for the Euler strut we need 10% as much mass. But for our 2nd generation fractal strut, we need 3% as much mass. For higher fractal generations, the efficiency continues to accelerate.

1.4.b Needs and advantages

Here we outline the different user needs, how we address them, and how our different competitors (Section 2.1.e) compare across them.

User need	*Problem to overcome*	*Our solution*
Lighter for a given strength	Applications in aerospace and space are weight critical: there are big advantages to making things lighter. For increased fuel efficiency, weight is the critical issue; aerodynamics and engine efficiency offer marginal savings.	Our fractal structures weigh less for a given strength. Recent advances in 3D printing in polymer and metal mean we can market to these weight-critical sectors, which are enthusiastic about additive manufacture, but lack expertise in efficient design.
Stronger for a given weight	Applications in the built environment are strength critical: there are big advantages to making things stronger. The size of tall buildings and broad platforms are limited by structure efficiency, but require big parts.	Our fractal structures are stronger for a given weight, and can be made with high linear dimension thanks to ingenious additive manufacturers which can print very long objects continuously on one end whilst ejecting it out the other.
Affordability	Strong, light structures must be affordable to a broad range of users. Some highly-publicized ultra-light materials are prohibitively expensive for industrial applications.	3D printing is expensive relative to mass-production methods, but cheap compared to competing technologies, e.g., micro-lattices. 3D-printing costs are declining fast, and do not depend on the complexity of the object.
Sustainability	Firms are under increased pressure to waste less material and adopt innovative technologies to achieve greater fuel efficiencies.	Our lighter structures leads to less material usage and, in the case of aerospace and space applications, the fuel and emissions associated with propelling them.
Agile manufacturing	Making new or modified designs takes a long time because it requires retooling the production process. Finding replacement parts is expensive and slow when they are not made locally.	All of our five classes of structures are designed for 3D printing, which is tool-less, can be done in small batches with *pro rata* cost, and can be done on or near site.
Design-manufacture integration	High-performance structures operate at the edge of what's possible, and their full potential can only be achieved if the design and manufacture are integrated.	We unify design and manufacture by optimising our structures specifically for 3D printing and, in this project, vice-versa, so each side harnesses the full benefit of the other.
Technology readiness	A number of breakthrough technologies for strong, light structures have been predicted in principle, but are far from real-world applications.	Most of our structures are at technology readiness level 6 or 7, meaning we are at least capable of producing a prototype in a production relevant environment.

User need	*Space frames*	*Micro-structures*	*Macro-structures*	*3D printed lattices*	*Carbon fibre*	*Fractal structures*
Lighter for a given strength	☆	☆☆☆☆☆	☆☆☆☆	☆	☆☆	☆☆☆☆☆
Stronger for a given weight	☆☆☆	☆	☆☆	☆☆☆	☆☆☆	☆☆☆☆☆
Affordability	☆☆☆☆☆	☆	☆☆	☆☆☆	☆☆	☆☆☆
Sustainability	☆☆☆	☆☆☆	☆☆☆	☆☆☆	☆☆	☆☆☆☆
Agile manufacturing	☆☆☆	☆	☆	☆☆☆	☆☆	☆☆☆☆
Design-manufacture integration	☆☆	☆	☆☆	☆☆☆☆	☆☆	☆☆☆☆
Technology readiness	☆☆☆☆☆	☆	☆	☆☆☆	☆☆☆☆	☆☆☆☆

2 Impact

2.1 Expected impacts

2.1.a Users and their needs

To accelerate market uptake and the commercialization of our product, we differentiate between early and final users. Early users make up a smaller fraction of the market, but they are key to generating early revenue. They also provide us with validated learning by testing our minimum viable product.

Early users

These are "the customers who feel the need for the product most acutely. [They] tend to be more forgiving of mistakes and are especially eager to give feedback" (Eric Ries, *The Lean Startup*). In terms of our product, early adoption is driven by defence, space and large component manufacturers.

Targeted user	*Specific user needs*
Government defence agencies	These big-budget agencies are looking for high-risk, high-reward next generation solutions to maintain a competitive advantage over adversaries. Applications include unmanned aircraft structures, components for manned aircraft, and satellite structures. An advantage of defence agencies is that they are willing to pay (on a commercial basis) for results 1–2 technology readiness levels lower than other customers. Examples include UK Centre for Defence Enterprise, US Office of Naval Research (seeking "high-loading/light-weight structural materials"), Defense Advanced Research Projects Agency.
Space agencies and companies	Accelerating and object into space requires many times its mass in fuel and launch vehicle. With launch costs for low earth orbit at $10,000–20,000 per kg, fractal structures will allow the deployment of larger craft, at a lower cost. Moreover, once a structure is deployed in space, it is both large and subject to light loads: precisely the conditions under which our designs are most advantageous. A more distant but intriguing application is solar sails, large platforms which accelerate by reflecting solar radiation. Example users include the European Space Agency, SpaceX, US Air Force Research Lab. (seeking "low-density materials...[for] airframes, space vehicles, satellites and load-bearing components").
Large original equipment manufacturers	These large manufacturers of aircraft and defence components have the in-house R&D commitment to explore third-party structure technology at TRL 6-7. They want a head start over their competitors on promising new technology. Examples include Safran, BAE Systems, Finmeccanica (now Leonardo) and Rolls Royce, as well as the dominant plane manufacturers themselves, Airbus and Boeing, which have internal venture subsidiaries with a strong interest in new manufacturing techniques and innovative materials.

Final users

As we continue to test, improve and validate our structures, we will turn to attracting final users: customers who are less risk-tolerant and more likely to adopt products that have had prior uptake.

Targeted user	*Specific user needs*
Airplane manufacturers	The two most pressing needs here are, first, lower fuels costs (fuel is an airline's single greatest expense) and, second, reducing greenhouse gas emissions (all airlines operating in Europe are subject to the "cap and trade" limits on emissions). Airbus, for instance, is already adopting hundreds of components in its A350 XWB. Other examples of manufacturers include Boeing, Bomardier, Dassault, Embraer, Gulfstream, Piaggio and Pilatus.

Small to medium original equipment manufacturers	These aircraft component manufacturers are aware of the growing range of opportunities at the intersection of additive manufacturing and aerospace, but do not have the in-house R&D commitment to explore third-party technology at TRL 6–7, preferring TRL 8–9. Examples include Aciturri (Spain), Martin-Baker (UK), Aero Vodochody (Czech) and Ducommun (US).
Elite racing	Turning away from aerospace and defence, high-end competitive racing sports tend to have big budgets and small winning margins. Sailing yachts and single-seat auto racing are on the lookout for new ways of gaining an advantage, often in the form of early-stage innovative technologies: yacht racing was an early adopter of carbon hulls as a means of reducing weight. Examples include the America's Cup and formula racing, such as Formula 1.

2.1.b Why users will pay

The seven user needs that we address in Section 1.4.a translate into seven user benefits which users will be willing to pay for.

Benefit	*Why users will value it*
Fuel efficiency	Fuel is a major expense for commercial and military aircraft. To put this into perspective, for a typical airline, the cost of fuel per flight is 2.9 times the cost of leasing the plane. Even modest reductions in weight translate into significantly less fuel consumption, saving airlines and defence agencies money.
Emissions targets	New emissions standards (the European "cap and trade" system) mean the aerospace industry must find new innovative ways of reducing weight, thereby cutting emissions. Our lighter structures will also help them achieve this.
Shorter turnaround times	Reducing the time of turnaround from concept to realisation makes firms more agile, meaning they can quickly adapt to changes in the market and respond to competition. They can also implement new technologies faster, which brings the cumulative advantage of an increased rate of innovation.
Sustainability	Lighter structures use less material, for a given strength. When these structures are made using additive, as opposed to subtractive, manufacturing, the savings is even bigger. (Subtractive manufacturing is used, for example, to machine strong, light unibody metal casings and exoskeletons.)
Design freedom	The combined result of greater structural efficiency and design-manufacture integration is more design freedom. Component shapes, hull geometry, aircraft dimensions and the elimination of parts are open to unprecedented possibilities.
Decentralized manufacturing, reduction in inventory	3D printing allows local needs to be met by local production, which translates into faster sourcing, a reduction in transport costs, and easier expansion into foreign and remote markets. When structural components can be "stored" as a design file and printed on demand, a physical inventory of spare or defunct parts is no longer necessary. This enables enhanced just-in-time production, and reduces waste from unused spare parts.
Proven optimality, manufacturing expertise	Our new structures are the result of our published theoretical research. Their proven optimality means that users can be confident in their efficiency gains. The international reputation of our two manufacturing partners means that users can be confident that failure modes have been studied and mitigated, and that the method of manufacture, stability testing, and post-processing state-of-the-art.

2.1.c Competitors

Overall there is no single dominant technology for strong, light structures. Instead, there is a variety of approaches, each with its own limitations. We do not compete directly with these technologies (compared across user needs in 1.4.a), but rather create new demand in an uncontested market space.

Spaceframes Threat level: low

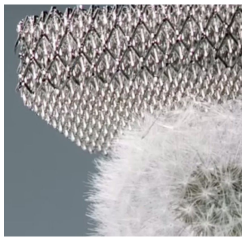
This includes structures based on the interlocking tetrahedral metal frame seen, for example, in many industrial roofs. Customised versions were once used as the structural skeleton of aircraft and cars. When arranged in a spiralling weave, it forms the ingenious geodetic airframe, used some early aircraft. The competitive threat is low, because it typically uses only one level of hierarchy. When it does use more, the design is heuristic rather than derived, and has not exhibited a new scaling law.

Examples
Wide roofs
Jaguar C-type
Louvre Pyramid
Vickers bomber

Microstructures Threat level: low

The essential advance here is miniaturization: the structures are latticed-based, but on a very small scale. HRL Laboratories developed a lattice of tiny metallic tubes that is extremely light, reaching 1/1000th the density of water, for a while the lightest material on Earth. A collaboration between Lawrence Livermore National Lab and MIT produced material as light as an aerogel, but much stiffer, also based on a microlattice concept. Both are strong for their weight, but not strong enough for the higher loads required by the users we describe.

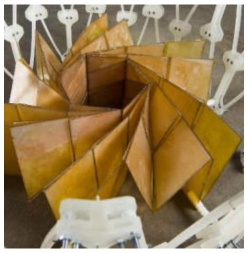
Metallic microlattices
Ultra-stiff material



Macrostructures Threat level: low

Here again the focus is on extreme lightness, but on very big rather than very small organizational length scales. These ingenious designs are intended for space, where loads are light. The goal is to make structures which become bigger than the launch vehicle carrying them. Applications include space stations, large solar panels and solar sails. For example, Caltech has developed deployable membrane structures for solar-powered satellites.

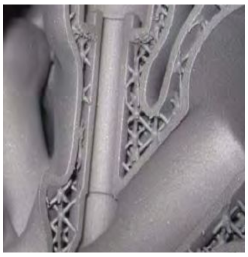
Space stations
Solar panels
Solar sails



3D printed lattice Threat level: medium

3D printing enables the production of previously impossible or financially impractical designs. One approach to making solid objects lighter is to fill the interior of the exoskeleton with a latticework, such as the automotive cylinder head, shown right. Open lattice structures are also used, without the shell. In both cases, however, the lattice is rarely optimized at a global level, nor involves multiple generations on different length scales.

Cylinder head
Airbus bracket
Irregular solids



Carbon fibre reinforced polymer Threat level: medium

This material, also known as carbon fibre, is used for bike frames, boat hulls and airplane parts. Half of the flagship planes of Boeing and Airbus are carbon fibre: 50% of the Dreamliner 787 and 52% of the A350 XWB. Carbon fibre is not new; rather, the manufacturing know-how and performance data have reached a tipping point where the material can be worked and trusted. A downside is that repairs are difficult: local damage requires large-scale replacement. Even with further optimization, this technology does not offer improved strength-to-mass scaling.

Surfboards
Racing bikes
Boat hulls
Airbus XWB
Boeing 787

2.1.d Market

Aerospace and defence

Global revenue for 2015 aerospace and defense is $706bn, according to Deloitte Global's report on the sector. Of this, the top eight European aerospace and defence companies, listed in Section 1.1.c, account for $150 bn. Globally, 2015 is 0.12% decline on 2014, driven by reduced defence spending; commercial aerospace, on the other hand, is set to grow an average of 4.4% per year over the next 20 years.

3D printing

Global revenue for 3D printing in 2015 was $5.1bn, according to the *Wohlers Report 2016: 3D Printing and Additive Manufacturing State of the Industry*—widely regarded as the leading guide to the sector. As Fig. 2.1 shows, the industry has expanded dramatically during the last six years. The compound annual growth rate of all 3D printing revenues over the last three years is 31.5%, according to *Wohlers Report 2016*. In other words, 3D printing is *doubling every 30 months*. Few sectors offer such an explosive growth opportunity. *Wohlers'* revenue forecast over the next six years is:

2015	$5,100,000,000
2017	$8,800,000,000
2019	$15,800,000,000
2021	$26,500,000,000

3D printing in aerospace and defence

The intersection of 3D printing and aerospace and defence is growing at a phenomenal rate. 3D printing has in the past been known for model building and prototyping, but this has changed dramatically. Final part production accounted for 51% of total revenue in 2015, up from 20% in 2010. This bodes well for our fractal structures, which are intended for final part use. The breakdown of innovation investment is shown in Fig. 2.2, according to a 2016 report released by Innovate UK. Aerospace and defence, our two strongest customer segments, make up 29% of the total. The following recent developments are extremely encouraging:

• Between early 2014 and mid-2016, Airbus, the leading European manufacturer, went from using just one 3D printed part in its aircraft to over 1000 in its flagship A350 XWB airplane (cf. Fig. 2.4).

• In 2015-2016, 3D parts were introduced by: BAE Systems for its Tornado GR4, Rolls-Royce for its Trent XWB-97 engine, GE for its LEAP engine, and Boeing for its F/A-18 Super Hornet and EA-18G Growler.

• In October 2016, Airbus announced plans to invest $15bn in 3D printing, with a focus on the Israeli 3D printing company Stratasys.

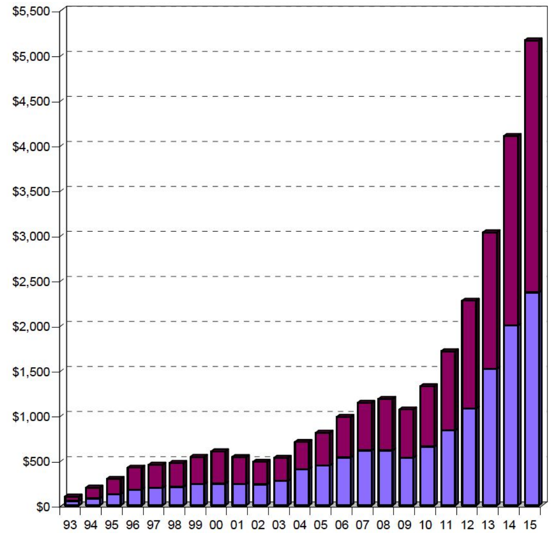


Figure 2.1. Growth to date: global revenue (in millions) for 3d printing products (lower blue segments) and services (upper burgundy segments). Source: *Wohlers Report 2016*.

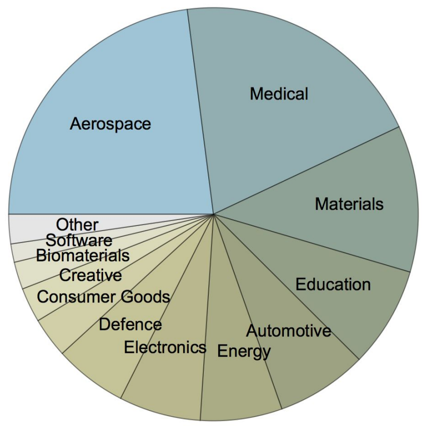


Figure 2.2. From the 2016 Innovate UK report on innovation in additive manufacturing. We do not include applications solely focused on enabling technologies.

Figure 2.3. An aircraft part redesigned for 3D printing to be significantly lighter (right). It was made by Airbus from a titanium alloy. "Perhaps more than any other major original equipment manufacturer, Airbus is planning a future that integrates AM [additive manufacturing] into production processes. An astounding variety of exploratory projects have been conducted using AM for metal and polymer parts." Source: *Wohlers Report 2016*, courtesy of Airbus.

2.1.e Impact on our consortium

Internationalisation. Our consortium partners will benefit from internationalisation in their respective markets. Prodintec and Ramem SA, our two manufacturing partners, have stronger experience with aerospace and users across Europe. StructX Ltd and the London Institute, on the other hand, have stronger experience with defence and UK and US users. By working together, both pairs of partners will extend their sectors and internationalise.

Design-manufacture integration. The partners in our consortium will also benefit from enhanced design-manufacture integration. The London Institute and the Italian CNR have experience in fractal mechanics and structure design. Ramen Ltd and Prodintec, on the other hand, have experience with polymer and metal additive manufacturing and post-processing. By unifying the design and manufacture into a single project, both groups will synergise by optimising their efforts so as to bring out the full benefit of the other.

Growth potential of our product. Our first use is the UK Ministry of Defence, which paid €162,000 for the design and manufacture of 10 fractal struts and two fractal shells. The global revenue of 3D printing is projected to grow from $5bn in 2015 to $26bn in 2021 (Section 2.1.d). Our revenue goal for the 36 months of this project is €2.8m, as outlined in Section 2.2.b. This translates into achieving a 0.06% share of projected final-part production in 2020.

2.1.f Other European and global impacts

We described economic impacts in Sections 2.1.a and 2.1.b. He we discuss other benefits.

Science of structures. Perhaps counter-intuitively, the science of efficient structures is at an early stage of development. Even some of the more basic structures were discovered relatively recently, which suggests that surprising new designs and advances are in store. The simple triangular Pratt truss, for example, wasn't adopted until the mid-19th century. This was extended by Alexander Bell to support a surface with the spaceframe, described in Section 2.1.c. The first geodesic dome was built in the 1920s but only understood quantitatively in the 1950s by Buckminster Fuller; this was a source of inspiration for the discovery of buckminsterfullerene. Fuller's counterintuitive notion of "tensegrity" comprises discrete regions under tension held in place by a continuous source of compression. Our consortium, in a series of papers over the last nine years, discovered the existence of fractal structures with new strength-to-mass scaling laws. With the design freedom afforded by 3D printing, it seems especially likely that innovative designs for mechanical advantage are at their infancy.

Sustainability. We mentioned earlier the benefit of more efficient structures in reducing emissions via the EU "cap and trade" system. Specifically, the European Commission on Climate Action states:

> The EU emissions trading system (EU ETS) is a cornerstone of the EU's policy to combat climate change and its key tool for reducing greenhouse gas emissions cost-effectively. It is the world's first major carbon market and remains the biggest one.

Reducing aircraft emissions is the number-one most effective way to curb climate change, and reducing aircraft weight is the most effective means of cutting aircraft emissions. And our project contributes to sustainability in another way. A large fraction of global freight is used to transport end-use parts between countries. By encouraging local additive manufacturing of our structures, we help alleviate this shipping need.

Job creation. In a special report on 3D printing, *The Economist* anticipates that "as manufacturing goes digital, it will change out of all recognition... And some of the business of making things will return to rich countries". With a strong presence in aerospace and defence and 3D printing, Europe looks set to have a resurgence in high-value manufacturing. Specifically, we anticipate 12–15 new jobs across the members of our consortium during the duration of this project; this will catalyse further job growth in the years subsequent.

2.2 Measures to maximise impacts

2.2.a Commercialisation strategy

StructX Ltd is the vehicle by which our consortium will commercialize our fractal structure products for use in aerospace and defence. StructX is the outcome of a nine-year journey of discovery, modeling, making and testing to bring ultra-strong, ultra-light structures to reality.

We will make money from our range of products (Fig 1.2) in three different ways: the three links in our value chain listed below. These progress from early users to late users. Our target revenue of €2.8m by the end of our 36 month project. We have already have a contract to manufacture, test and deliver 12 structures to the UK Ministry of Defence for €162,000.

i. Physical prototypes *Early users*

The first link in our value chain is physical prototypes which we design, manufacture and post-process and test. Early adopters of our technology will be defence agencies and large original equipment manufacturers. In the following tables, we have used our Ministry of Defence contract as a baseline for costs and sale price, adjusting to account for a reduction in price for larger orders. We average over typical variations in manufacturing and post-processing in polymer and metal, and size.

	Strut	*Plate*	*Shell*	*Filling*
Cost of updating existing design	€300	€200	€500	€600
Cost of 3D printing	€400	€300	€500	€700
Cost of post-processing and testing	€300	€200	€400	€500
Sale price (excluding VAT)	€4000	€3000	€5000	€6,000
Profit	€3000	€2300	€3600	€4200

ii. Custom designs *Early and final users*

The second link in our value chain is customised designs, which may vary in shape or curvature. Customers in this case include early users above and also lae user: airplane manufacturers and small to medium equipment manufacturers. These designs will be manufactured and post-processed by us for the purposes of demonstration, but in general the customer will be buying the design for in-house manufacture of their own or with their established manufacturers. We will advise on alloy, potential performance gains, load limits, fatigue and fracture data, and fractal structure vs conventional structure cost-benefit analysis.

	Custom strut	*Custom plate*	*Custom shell*	*Custom filling*
Cost of custom design	€1200	€800	€1600	€2400
Sale price (excluding VAT)	€4000	€3000	€5000	€7000
Profit	€2800	€2200	€3400	€4600

iii. Standard design repository *Final users*

Finally, we will develop a design repository in which users can download standardized structural components for a fee. This forms the third link in our value chain, and it requires the least customization, making our variable costs per design download small. We estimate the typical cost of a fractal structure design to be €500-€1500, with a mean of €1000.

We estimate the following market uptake of our products, where different structures show different uptake rates based on their breadth of functional use on their TRL development:

Physical prototypes

		Strut	*Plate*	*Shell*	*Filling*	*Total of all types*
Q5–Q6	units sold	24	0	8	0	€101
Q7–Q8	units sold	24	12	16	8	€191
Q9–Q10	units sold	36	24	24	16	€317
Q11–Q12	units sold	48	36	32	24	€443
Total revenue (1000s)		€396	€166	€288	€202	€1052

Custom designs

		Custom strut	*Custom plate*	*Custom shell*	*Custom meta*	*Total of all types*
Q5–Q6	units sold	6	4	8	2	€62
Q7–Q8	units sold	12	8	12	4	€109
Q9–Q10	units sold	24	16	24	8	€221
Q11–Q12	units sold	48	32	48	16	€442
Total revenue (1000s)		€252	€132	€312	€138	€834

Standard design repository

		Strut-based	*Plate-based*	*Shell-based*	*Meta-based*	*Total of all types*
Q5–Q6	units sold	10	8	8	0	€26
Q7–Q8	units sold	20	16	16	8	€60
Q9–Q10	units sold	40	32	32	16	€120
Q11–Q12	units sold	80	64	64	32	€240
Total revenue (1000s)		€150	€120	€120	€56	€446

Timeline of revenue

Based on our existing agreed contract, the above market uptake estimates, and a plausible estimate of a further defence contract, our timeline of revenue is as follows. It total €2.8m. The growth represents both an increase in users, as well as an increase in the range of products (structures types) available, from one in the beginning to four by the project end.

Months 1–6	Current 8-month UK Ministry of Defence contract	€162,000
Months 7–12	Extension of MoD contract (we are in discussions now) OR a defence contract with the US Department of Defense (DARPA, ONR or AFOSR). The amount is based on prior 2-year contracts our consortium has had with the US DoD.	€360,000
Months 13–18	From the combined Q5–Q6 sales	€189,000
Months 19–24	From the combined Q7–Q8 sales	€360,000
Months 25–30	From the combined Q9–Q10 sales	€658,000
Months 31–36	From the combined Q11–Q12 sales	€1,125,000

The EU contribution for the FTI Pilot is 70% SMEs, and 100% for non-profit organizations. For StructX, the 30% difference will be made up from the UK Ministry of Defence (€162,000), founder investment (€138,000), and profit from the sales in our market uptake above. For Ramem SA, the difference will be made up from profit generated from sales and the use of man-months and/or equipment rental used in the project and covered by the company.

2.2.b Dissemination and communication

Dissemination (D) is about promoting our product through PR, social media and advertising; communication (C) is about promoting our product in other ways.

Activity	*Audience*	*How we will do it*
PR (D)	Aerospace	This is a combination of meeting leaders in the applicable firms via London Inst. and Ramen SA, who is familiar with them, writing for industry magazines and appearing at the trade shows described below.
Research publications (D)		Publication of basic science results in scientific journals.
Inform industry monitors (D)	Early and final users of 3D printing	We will make ourselves known to the key industry handbooks and monitors, with the goal of getting StructX listed as a provider of efficient structure solutions. Being listed in *The Wohlers Report*, for example, is an excellent source of free advertising (Prodintec is already featured).
Aerospace and 3D printing conferences and trade shows (C)	Market leaders, early-	Additive Manufacturing Europe — Amsterdam — 2017 5th Annual Aerospace Manufacturing — Dearborn, US — 2017 Noah Leaders Connected — London; Berlin — 2017 Strategies for Additive Manufacturing in Aerospace, Defence and Space — London — 2018 AM3D Conference and Expo — N. Carolina, US — 2018 Advanced Design of Light Aircraft — tbc, UK — 2018
Pitching for investment (C)	VC firms, investors	As we commercialise our product beyond Europe, we will seek support from venture capital firms and angel investors. We will to pitch to investors, such as London-based Balderton Capital, with the intention of accelerating our expansion. We hope to use the SME Instrument mentoring programme to hone our skills in this area.
Intern, student recruitment (C)	Interns and potential long-term employees	Will will host three-month summer intern projects for students on structure design and stability analysis. This will attract bright minds to work with our team without having to commit spend a lot of money. Interns will be mentored by a senior team members. Gabrielli and Fink have experience mentoring student projects.
Targeted pitching (D)	Early-users: defence	We will direct contact likely UK, US and EU defence agencies who have made clear their search for strong, light structures (we list examples in Section 2.2.b).

Our team has experience in securing contracts US with contracts, including the Defense Advanced Research Projects Agency and the Defense Threat Reduction Agency.

2.2.c Knowledge protection, freedom to operate and open access

Knowledge protection

In devising our plan to protect IP and exploit our results, we considered the reports *IP Management in Horizon 2020,* and *Commission recommendation on the management of IP*.

Our consortium owns all of the exploitable IP involved in this project. We have a consortium agreement in which current and future specific designs of fractal structures, and the computational methods and code used to test them, belong to StructX; and remaining IP belongs to that consortium partner which created it. Furthermore, we note the following potential IP and its status:

Potential IP	*Status of protection*
Proprietary structure stability modelling code	StructX owns copyright
Proprietary visualization rendering code	StructX owns copyright
Copyright of .stl design files and rendered images uploaded to our structure repository	Protected for 15 years by Database Directive (96/9/EC of European Parliament)
'StructX' name	StructX is seeking trademark protection in the UK
Global trademark protection	We will extend trademark as and when we enter new territories (activity in a territory is a prerequisite for trademark protection)
Patents on self-similar hierarchical (fractal) structures exhibiting new strength-to-mass scaling laws	We have not found any competing patents which could impede us. We will file appropriate patents of our own by August 2017.

Freedom to operate

We have the freedom to operate in all of the EU countries in which we plan to operate: Austria, Denmark, France, Germany, Hungary, Ireland, Italy, Poland, Spain, Sweden, UK. We also have freedom to operate in America and Israel, two countries which have strong markets in aerospace and defence and 3D printing.

Our discovery of fractal structures was published in a series of research papers over the last nine years by members of our consortium. Being published, the mathematical theory described therein is in the public domain. However, the practical IP and know-how of optimising and making the structures remains proprietary: our computational methodology, stability analysis, 3D rendering code, perturbation methods and optimal material parameters. It also includes our teams' know-how in executing defence and aerospace contracts and additive manufacturing jobs.

Open access

Most of the work in this proposal involves the optimisation, manufacture, improvement and commercialisation of our fractal structures, and is inappropriate for academic publication. However, some fundamental research outputs—mainly concerning mathematically derived new fractal structures—may be published in scientific journals.

The Horizon 2020 "Guidelines to open access" describes two types of open access: self-archiving and open access journal publication. Results for which it is appropriate to publish will be (i) made available on the arXiv online repository and the dedicated website for this project; and (ii) be published in open-access journals.

Open research data scheme

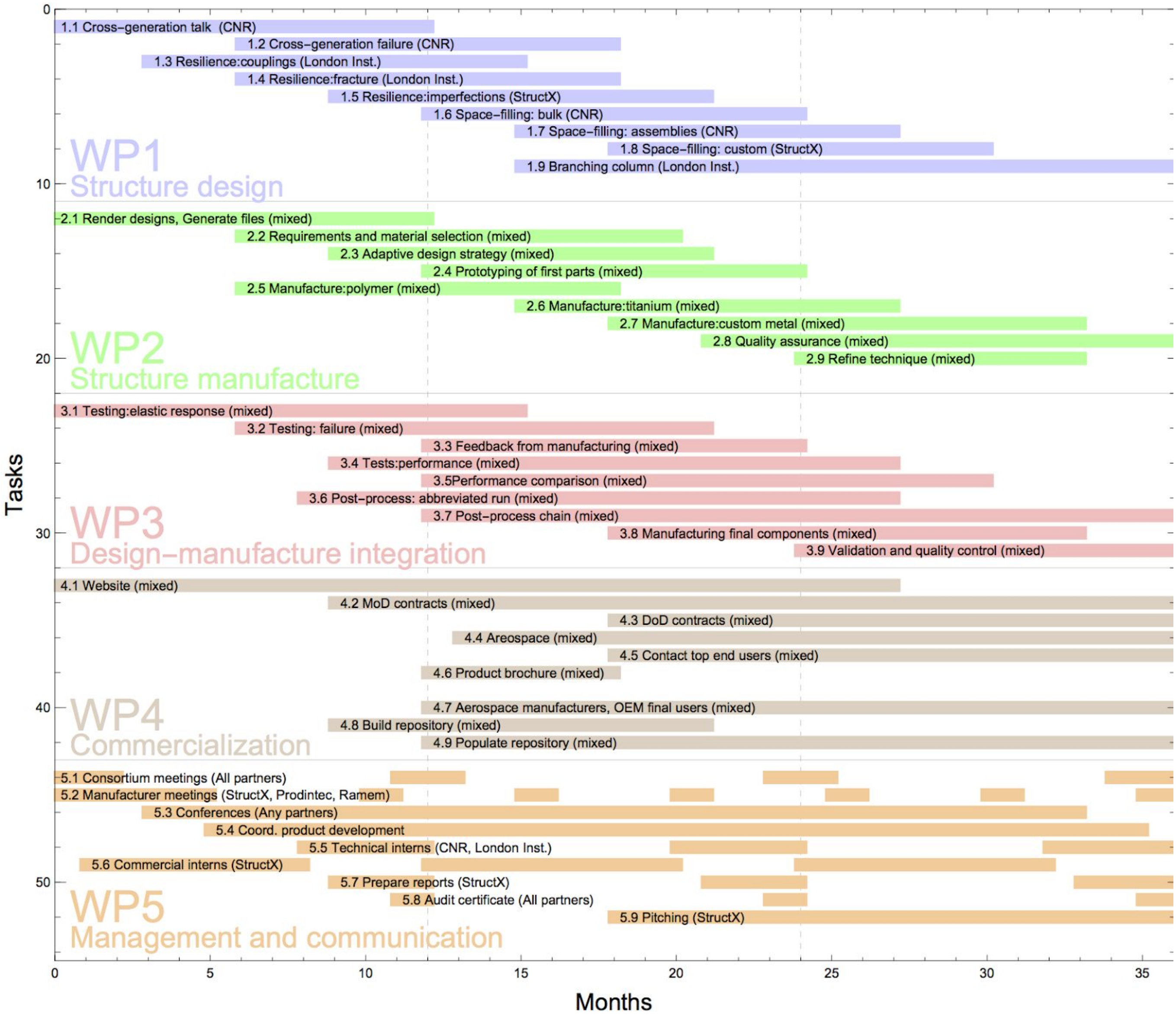
We will not take part in the optional pilot Open Research Data scheme.

3 Implementation

3.1 Work plan

3.1.a Timeline of work packages and tasks

	Work package	*Lead partner*	*Person months*	*Start month*	*End month*
WP1	Designing structures	CNR/London Inst.	82	1	36
WP2	Manufacturing structures	Prodintec	62	1	36
WP3	Design-manufacture integration	London Inst./Ramem	97	1	36
WP4	Commercialization	StructX/Ramem	78	1	36
WP5	Management and communication	StructX	41	1	36



3.1.b Deliverables

	Deliverable	*WP*	*Type*	*Dissem. level*	*Deliv. month*
D1	Report on the structure resilience to local defects or buckling	1	R	PU	12
D2	Report on feasibility of space-filling structure for manufacture	1	R	PU	18
D3	Performance summary on our fractal structures manufactured in polymer (three of our four types)	2	R	PU	15
D4	Performance summary on our fractal structures manufactured in metal (three of our four types)	2	R	PU	30
D5	Report on success and hurdles in post-processing & quality control	3	R	PU	21
D6	Summary of performance improvements over three build-test-learn cycles	3	R	PU	30
D7	Website showcasing our product range and value chain	4	Dec	PU	8
D8	Report on aerospace investment/sales by early and final users	4	R	PU	30
D9	Annual reports following our consortium-wide meetings	5	R	PU	14, 26
D10	Presentation for pitching to investors for accelerating growth	5	R	PU	30

LEGEND R = document, report Dec = websites, press/media Oth = software, etc. PU = Public

3.1.c Detailed work plan

WP1 Designing structures Months 1–36

Objectives O1 Develop techniques to better understand cross-generational instability coupling.
O2 Determine global structure resilience to local defects or buckling.

	Task	*Description*
1.1	Cross-generation talk	Develop recursive techniques for understanding couplings between instabilities at different hierarchical levels. Find closed solutions or if need be approximations for any new buckling modes.
1.2	Cross-generation failure	Study propagation of failure from small to large length scales. Determine how controlled over-design can provide resilience to defects and overloading. Characterize trade-off between robust and light.
1.3	Resilience: couplings	Analyse how fixed-joint couplings between different hierarchical levels and controlled over-design can restore resilience under defects and overloading.
1.4	Resilience: fracture	Analyse the resistance to brittle breaking under tension or bending strains, and the propagation of failure sites to estimate toughness.
1.5	Resilience: imperfections	Model the effects of manufacturing imperfections and cross-talk between hierarchical levels, and resultant reduction in expected safe loads.
1.6	Space-filling: bulk	Enumerate space-filling formations of fractal struts to form a fractal meta-material. Calculate stiffness and compressive strength.
1.7	Space-filling: assemblies	Calculate the revised bulk strength of space-filling assemblies from the revised properties of the engineered unit cell. Model the consequences of lattice defects in assemblies on crush strength.
1.8	Space-filling: custom	Combine fractal design with cellular structure optimisation to produce space-filling material customized for a given specific distributed loading.
1.9	Branching column	Calculate buckling modes for branching column truss. Determine optimal branch angles and rod lengths. Add cross-column separators if necessary.

WP2 Manufacturing structures Months 1–36

Objectives O3 Three of our five structure types 3d-printed in polymer, three in metal.
O4 Test structures.

	Task	*Description*
2.1	Render designs, generate files	Render our fractal designs using CAD software and in-house converter developed StructX. Create slice files or standard .stl design files.
2.2	Requirements and material selection.	Study of geometrical and morphological features of the fractal structures to be implemented by means of 3D printing technologies. Analysis of main requirements regarding points such as minimum size of the unitary block, wall size, etc. in order to be feasibly printable by means of the particular techniques proposed in the project. Besides, material selection will be carried out, by studying mechanical properties and operational behavior of the available ones for this particular technology.
2.3	Adaptive design strategy	Adaptation of designed models with the main objective of matching DMLS process philosophy and building strategies/mechanisms. Hence, several points are considered here like nesting, part orientation within machine operative volume, reduction of potential geometric/dimensional distortion and operative issues like stuck loose powder, support structures removal.
2.4	Prototyping of first parts	In a first stage from the manufacturing approach, proofs of concepts will be printed through DMLS techniques in order to verify that the chosen strategy and design adaptation fits the final requirements of the application. Test parts will be built in order to characterize critical factor such as surface finishing and dimensional accuracy.
2.5	Manufacture: polymer	Manufacture our fractal structures using selective laser sintering of polymer over a range of 1st generation and second generation volumes.
2.6	Manufacture: titanium	Manufacture our structures using electron beam and/or laser sintering in titanium alloy, over 1st and 2nd generation range of volumes.
2.7	Manufacture: custom metal	Depending on industrial user needs, manufacture customised structures in titanium alloy or other metal.
2.8	Quality assurance	Monitor surface roughness and minimum viable strand width for quality assessment and feedback into design-manufacture integration.
2.9	Refine technique	Perform two to four iterations of build-measure-learn to improve the manufacture of our structures. Variables in include number of generations, material type and finishing process.

WP3 Design-manufacture integration

Months 1–36

Objectives O5
O6

	Task	*Description*
3.1	Testing: elastic response	Perform structural tests, with medium speed digital video, to determine elastic response
3.2	Testing: failure	Measure failure loads and determine failure modes using full-field digital video to capture deformation/collapse history.
3.3	Feedback from manufacturing	Using the body of data collected in from WP2, optimise design parameters, including the possible variable width rods in the struts and meta- structures.
3.4	Tests: performance	Compare the elastic response and failure loads of our fractal structures and meta-material to non-fractal alternatives.
3.5	Performance comparison	Map out the parameter space where fractals are practically superior to conventional alternatives.
3.6	Post-process: abbreviated run	Post-process the structures, including surface cleaning and smoothing, heat treatment for eliminating defects and fracture nucleation sites, and machining and testing for strength and tolerances demanded by our aerospace and defence users.

3.7	Post-process chain	DMLS parts require post processing operations in order to improve surface roughness and correct potential deviations within sintering process (mainly due to internal thermal stresses). Study path to post processing operations, using several mechanical technologies, such as material removal technologies (milling) and final surface treatment (polishing).
3.8	Manufacturing final components	Begin final components defined as targets for the project application in aeronautics field. The cycle should be tuned up in order to match particular requirements for the final shapes and designs, which may require specific treatment besides considerations intrinsically related to fractal structures.
3.9	Validation and quality control	Validate final parts in two ways: surface quality and geometric /dimensional accuracy. The first involves original roughness of the DMLS part, and the reduction due to the proposed post process chain. The second relates to the dimension stability for the integrated process chain.

WP4 Commercialization

Months 1–36

Objectives O7 Leverage MoD prototypes to gain further defence contracts (EU or US).
O8 Win aerospace contracts using market brochure and specifications of our product range

	Task	*Description*
4.1	Website	Develop website to outline structure types, the three stages of our value chain and our design repository.
4.2	MoD contracts	We will have delivered our final batch of MoD designs well before this Phase 2 begins. In Phase 2 we will be seeking to renew and extend the contract to build more operation-ready structures.
4.3	DoD contracts	Submit bids to US Air Force AFOSR-2015-0001 and US Navy N00014-16-R-BA01, which seek SME's to build light structure prototypes.
4.4	Aerospace	Develop range of ready-to-design structures which will be bought by the aerospace industry, which will use its own additive manufacturers.
4.5	Contact end-users	Market directly to the original equipment manufacturers (OEMS).
4.6	Product brochure	Develop a product brochure describing struts, plates, shells, space-filling materials and distribute to trade shows, potential early/final users.
4.7	Aerospace manufacturers, OEM final users	Led by Ramem SA's industry familiarity, we will meet with representatives of the key EU aerospace companies described earlier.
4.8	Build repository	Build online structure repository, including a way to visualize the different designs and an online payment system.
4.9	Populate repository	Populate the structure repository. This is a continuous task done as and when we develop and test new structures and materials.

WP5 Management and communication activities

Months 1–36

Objectives O9 Find and hire technical and commercial interns.
O10 Orchestrate the team leaders and partners to keep our scheduled pace.

	Task	*Description*
5.1	Consortium meetings	The five members of our consortium will all meet for a kick-off meeting, and towards the end of the first, second and third years, rotating countries.
5.2	Manufacturer meetings	Meet regularly with our manufacturers Prodintec and Ramem SA to assess progress and challenges.
5.3	Conferences	Communicate, disseminate product brochure at conferences (e.g., Noah Leaders Connected, London and Berlin) and trade fairs (AM, aerospace).
5.4	Coord. product development	Farr and our project manager will coordinate and align the activity of our consortium on the WPs and tasks therein.

5.5	Technical interns	Recruit students for summer projects on stability analysis, fractal scaling laws, and computer modelling of new prototypes prior to manufacture.
5.6	Commercial interns	Recruit interns to help with our marketing campaign, distributing our product brochure and representing us at aerospace and AM trade fairs.
5.7	Prepare reports	Our project manager will collect progress reports from our team, which will be synthesized into one report and delivered by project leader Farr.
5.8	Audit certificate	Comply with H2020 audit requirements after hitting the €325,000 threshold. This will be organized by our project manager.
5.9	Pitching	Expand our effort to seek venture capital and angel investment during the last 12 months when our product has received greater traction.

3.2 Management, milestones and procedures

3.2.a Management structure

Lead team. The lead team is made up of
Robert Farr (StructX Ltd),
Silvia Vidal Lopez (Ramem SA),
Andrea Gabrielli (CNR),
David Gonzalez Fernandez (Prodintec),
Thomas Fink (London Inst.)

Operations manager. We will appoint a project operations officer. The officer is responsible for: hiring and assisting staff; synchronising the work packages and tasks therein; logistics of our marketing campaign; ensuring budgets are correctly allocated; assisting with the H2020 annual reports; and complying with the audit and the audit certificate.

Work package leaders. The leaders of the four work packages are as follows:
WP1 Robert Farr (StructX Ltd)
WP2 Silvia Vidal Lopez (Ramen SA)
WP3 Andrea Gabrielli (CNR)
WP4 David Gonzalez Fernandez (Prodintec),
WP5 Robert Farr (StructX)

Decision-making mechanisms. The three members of the lead team, along with the operations manager, will form a project Board to ensure that the work is successfully implemented, subject to the risks and mitigations below. The Board will align the tasks within the work packages, taking into account any interdependencies. Final decision making will rest with the chair of the Board, Farr.

Appropriateness of mechanisms. The structure and mechanisms described here are in proportion to the size and complexity of our team. We have distributed responsibility and have prepared detailed tasks (Sections 3.1.c) within the work packages and set milestones (Section 3.2.b) which will help us chart our progress and pace ourselves appropriately. We outline the challenges and risks that we are most likely to encounter and how we will overcome or mitigate them (Section 3.2.d).

3.2.b Milestones

	Milestone	*WP*	*Month*	*Means of verification*
M1	Website	4	4	Website is up and shows our range of structure types
M2	Manufacturing in polymer	2	12	Three of our four structure types are manufactured in polymer in a range of volumes and dimensions.

M3	Manufacturing in metal	2	24	Three of our four structure types are manufactured in in titanium or other alloy, in a range of dimensions.
M4	Post-processing	3	27	Our metal structures manufactured in metal are surface treated, machined and tested for size and strength.
M5	Product brochure	4	8	A concise pdf which we can distribute to users and potential customers summarising our product, user needs and how we address them, and manufacturing technology.
M6	Internal and annual meetings	5	1, 6, 12, 18, 24, 34	Official reports for months 12, 24 and 34; minutes of meeting for months 1, 6 and 18.

3.2.c Innovation management

The manufacturing industry and science has a well-developed understanding of the basic mechanics of structures, so it is natural to imagine that our intuition for the possibilities of strong, light structures is sound. But this is far from the truth. The reality is that our structural intuition is highly influenced by the design process itself, which has throughout history been constrained by notions of subtractive manufacture (carving and sculpting), modular assembly, casting, forging and our inability to access enclosed spaces. Certainly our intuition is poor for how and why structures break or fall down. More surprisingly, it also fails us on simpler fronts, like the limits of structural strength (for a introductory essay, see http://www.london-institute.org/people/farr/fractals.shtml). Remarkably, fractal structures can offer in principle unlimited mechanical advantage, in the sense that a small amount of matter can support an unboundedly larger amount of force. In practice, this is limited by the resolution of manufacturing techniques and the continuum mechanics approximation (atoms exist!). This makes explosive growth of additive manufacturing especially relevant to industry: it removes most of these constraints. By combining these new manufacturing possibilities with our consortium's discoveries in fractal structures and mechanics, we are at the centre of a perfect storm for accelerating and commercialising innovation.

Key to managing this innovation is a strong integration of the design process and method of manufacture. As we have described elsewhere, design-manufacture integration is key to our project, and we take concrete measures to achieve it:

- Project leader Robert Farr has a hybrid background of academia and 12 years product development at Unilever.
- In addition to our consortium-wide meetings, we have scheduled regular visits to manufacturer Prodintec's premises
- Our partner Ramem SA works directly with aerospace and defence contractors and manufacturers, and by working with them and visiting users directly, we will keep keep our products industry-focused.
- By performing multiple iterations of build-measure-learn, we will optimise design to enhance the manufacturing strengths, and revise manufacture to take full advantage of our design possibilities.

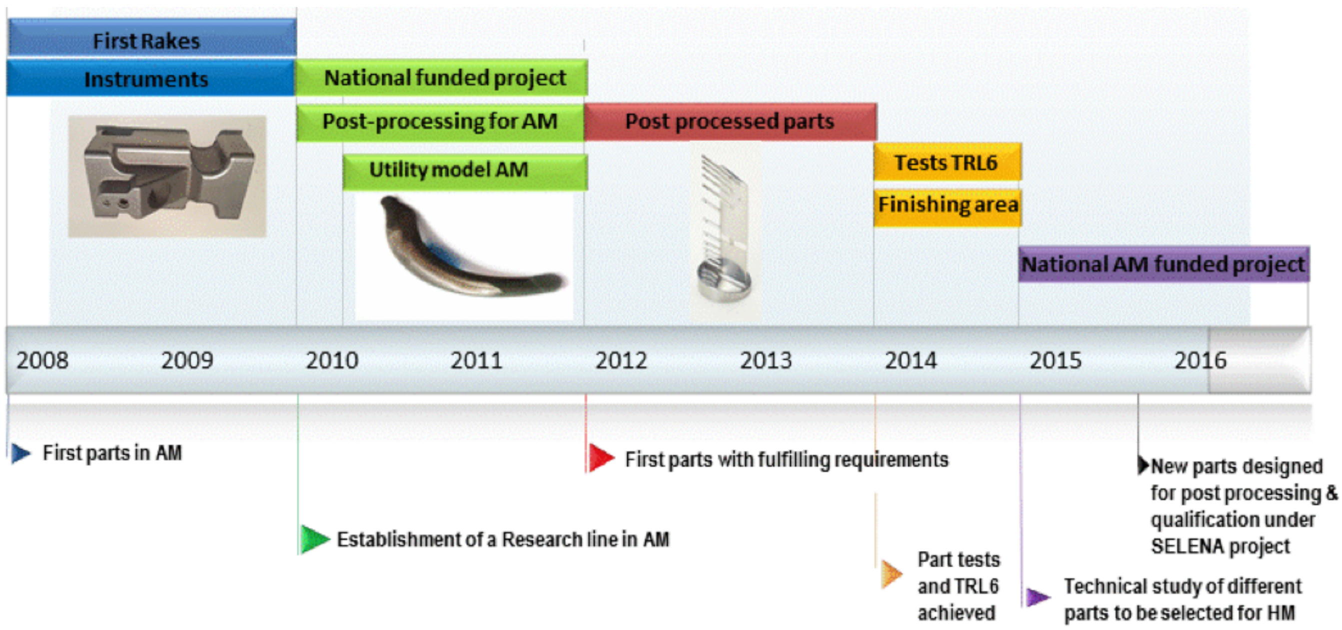


Figure 3.1. Timeline of innovation experience at partner Ramem SA.

3.2.d Risks

- *Technical risks* relate to unexpected difficulties in implementing our technology.
- *Commercial risks* relate to unexpected events in how users derive value and we generate growth.

	Technical risk	*Mitigation*
R1	Unpredicted failure mode	The risk is that, in our theoretical stability analysis, our freely-pinned approximation to rigid manufactured joints breaks down, and unexpected failure modes arise. To mitigate this, if it arises, we will enhance the structure in question to have stabilising cross-links; an example of this can be seen in in our strut in Fig. 1.2, where the second-generation truss has five interior stabilising triangles.
R2	Inconsistent quality control	3D printing is capable of high precision. Over long production runs, however, it can show a lack of consistency, compared to more mature manufacturing methods. To mitigate this, Prodintec will conduct quality assurance tests, and Ramen SA quality assurance tests, to ensure correct manufacture.
R3	Size limitations	Most 3D-printing machines have fixed bounds on the dimensions of the product they can make (0.5 to 2 metres, depending on the technology), just like the image size in an ordinary printer. If the need for larger parts arises, we will turn to using an ingenious fix in which the production process is turned on its side: the Voxeljet's VXC800 can make very long objects by continuously printing on one end, at the same time ejecting the structure out the other.
R4	Structure does not perform as predicted	The risk is that one of our structures does not perform as predicted, for example, exhibiting poor strength performance over user-required length scales. To mitigate this, we will use our five structure types—strut, plate, shell, volume, truss—to absorb this, commercializing those structures which do perform as expected. At the same time, we continually seek to discover other fractal structures with improved strength-to-mass scaling relations.
	Commercial risk	*Mitigation*
R5	Replication by competition	The risk is that a competitor tries to copy our concept starting from our published research papers. This is mitigated in three ways:

		First, while our general theory is published, our crucial application-specific theory and know-how is proprietary. This includes our stability analysis methods and code, perturbation theory, and optimal parameter data. Second, we make continual design improvements as we learn how different materials and techniques perform (WP3: Design-manufacture integration). Third, we have a brand advantage: we were first to discover fractal structures, and we will emphasize to customers that we are best placed to make them.
R6	Pirating of designs	The risk is that a user buys one of our designs, and then distributes it online where it is pirated. If this arises, we will mitigate future instances by including in each .stl file a unique "signature" whereby a local region of the structure is slightly over-engineered. This will not be detectable in the structure itself, but will in copies of the design file, identify the source of the leak.
R7	Growth but little revenue	We outlined three main links in our value chain: physical prototypes, custom designs, and a fee-based repository of designs for download (Section 2.2.a). If overall revenue is poor, we will adjust the spread along our value chain portfolio, reinforcing the most profitable links.
R8	Revenue but little growth	Our initial engine of growth is targeting specific potential customers, selling them a single prototype at first, and then expanding the breadth (struts, plates, shells, filling, truss) and depth (designs customised to specific shape or stress needs) of products. If necessary, we will shift to PR/advertising engine of growth to attract customers beyond our initial target base.

3.3 Consortium as a whole

Our consortium has five partners. Two of these, StructX and Ramem, are SME partners, and together account for over 60% of the budget. A third partner, Prodintec, while technically a non-profit, is an SME in practice; Prodintec is the industry focused body. The fourth and fifth partners, CNR and the London Institute, are academic institutions which have played a strong role in the

3.3.a Experience of consortium and partners

Our consortium has the technical, market and business skills to commercialize our product:

Technical skills	*Market skills*	*Business & management skills*
Mechanical engineering	3D printing in polymer	International contracts
Fractal mechanics	3D printing in metal	Managing teams of 5–25
Fractal geometry	Aerospace industry	Recruiting, guiding interns
Elastic buckling	High-performance alloys	Managing defence contracts
Structure computer modeling	Securing defence agency contracts	Experience founding start-ups
Physical structure testing	UK Ministry of Defence contracts	Leading skunkworks teams
Statistical mechanics	Original equipment manufacturers	Commercial R&D
3D graphics rendering	Aerospace component procurement	Industrial R&D (12 yrs Unilever)
Mathematica programming	Academic-industrial interface	

	Technical experience	*Commercial experience*
StructX Ltd	Fractal mechanics Elastic buckling 3D graphics rendering	UK defence contracts (MoD) Industrial R&D Managing teams of 5–25 Commercializing products
Ramem SA	Post-processing Structure testing	Hybrid manufacturing completed with most advanced and innovative surface finishing systems on the market: Manual, automated and semi-automated processes for

		deburring, polishing and surface hardening, which include abrasive, thermal, chemical, electrochemical and magnetic techniques.
CNR	Fractal geometry Statistical mechanics	Lectures and participation in CCS conferences "Social and Economic Change as a Complex Dynamical System" in Rome and Arizona USA.
Prodintec	3D printing in polymer 3D printing in metal High-performance alloys non-metallic materials (Polyethylene, Polypropylene, Teflon, PVDF, PEEK, Methacrylate).	Development of new manufacturing technologies, improving existing production processes. Extensive experience in materials and can manufacture prototypes, machining in metallic materials such as Steel, Stainless steel, Aluminium, Titanium, Inconel, Cobalt-chromium, Copper, Brass, Molybdenum.
London Institute	Mechanical engineering Fractal structures etc	US Defence contract (DARPA, DTRA). Advising MOD on new Innovation award scheme.

3.3.b Role of each consortium partner

Partner	*What they will do*	*Why we chose them*
StructX Ltd	Vehicle for commercialising our product / Strategy for product development / Lead the consortium / Manage SME partners / Lead computational analysis	StructX Ltd is a company that spun out of the nine-year endeavour to discover and make ultra-strong, ultra-light structures
Ramem SA	Post-processing for aerospace / Commercialisation to aerospace and defence / Final machining and quality control	Ramem SA have more than 55 yrs experience in industry and manufacturing. They oversee more than 20,000 items throughout the whole lifecycle of the products. Participated in the A350, A380, A400M, Eurofighter, Tiger, Meteor, EJ200, XWB, Trent and TP400 programme. Manufactures parts for aircraft flight parts, motors and systems in materials such as titanium, aluminium alloy, stainless steel, chromium-nickel,technopolymers.
CNR	Lead structure design and analysis	The Complex Systems Institute at the CNR, based at La Sapienza, is well known for fractal research and the collective behaviour of complex systems. Gabrielli has worked with Fink previously.
Prodintec	3D-printing in polymer 3D-printing in metal	Prodintec are leaders in the field of industrial design and production. Registered in 2007 as Innovation and Technology centre (no.99). Are able to advise on manufacturing technologies and on the most suitable materials based on our product's specifications, use, expected manufacturing costs, the number of parts... They can make technical and economic assessments

			on the potential of using new materials in existing manufacturing processes.
London Institute	Design-manufacture integration New structure designs Manage academic partners		London Institute has worked on fractal structures over the last four years. Fink has worked on fractal branching columns and scaling relations and supervised students on the subject. .Farr has been a visiting scientist at the London Institute for two months a year. Fink is has worked on fract

3.4 Resources to be committed

3.4.a Summary of personnel

We have a total of 360 person-months over the 36-month duration of this project. These break down into the respective work packages as follows:

Participant	*WP1 Design*	*WP2 Manufacture*	*WP3 Design-manuf. integration*	*WP4 Commercial-ization*	*WP5 Management & communication*	*Total*
StructX Ltd	10	18	30	42	17	117
Ramem SA		10	20	30	3	63
CNR	44		24		4	72
Prodintec		34	3		3	40
London Institute	28		20	6	14	68
Total	82	62	97	78	41	360

EC-related management accounts for 6% of the total budget, as per Horizon 2020 guidelines.

StructX Ltd will have a total of 117 person-months (this includes the EU and non-EU contributions): 72 pm of junior members' time, 32 pm of senior members' time, and 13 pm of EC-related management. The junior members' time includes one 36-month structural mechanics modeler, one 24-month operations manager, and one 12-month aerospace and defence market specialist.

Ramem SA will have a total of 63 person-months (this includes the EU and non-EU contributions), which will three senior and two junior members of the company.

CNR will have a total of 72 person-months: 60 pm of junior members' time and 12 months of senior members' time. The junior members' time includes one 2-year postdoc and one 3-year postdoc. The senior members' time includes two senior researchers.

Prodintec will have a total of 40 person-months: 18 person-months of senior members' time and 22 person-months of junior member's time.

LIMS will have a total of 68 person-months: 40 pm of junior-members' time, 20 pm of senior members' time, and 8 pm of EC-related management. The junior-members' time includes one 2-year postdoc and one 1.3-year postdoc. The senior time includes one Fellow and a senior associate.

3.4.b Other direct costs

Please complete a table if the sum of the costs exceeds 15% of the personnel costs for that participant.

The total of Other Direct Costs does not exceed 15% of the personnel costs for any of the members of the consortium.

4 Members of the consortium

4.1 Participant: StructX Ltd

4.1.a Description of the legal entity

StructX is a London-based company headed by Robert Farr. StructX makes ultra-strong, ultra-light structures for aerospace, defence and the built environment. It works closely with the additive manufacturing sector to combining the founding team's research on fractal structures with recent advances in 3D printing. The endeavor to make fractal structures has been in progress over the last nine years, when they were first discovered, and StructX was formed to fully commercialize on this development as new structures, prototypes, contracts and revenue begin to accelerate.

4.1.b Key persons

Dr Robert Farr (male) read physics at Cambridge, where he won the Clerk Maxwell University Prize for physics, then sat the Mathematical Tripos Part III. He did his Ph.D. at the Cavendish Laboratory, Cambridge with Robin Ball. He is currently a research scientist at Unilever and has a number of visiting appointments to British universities, including Nottingham where he supervised a PhD student in fractal structures (R.-Kirkhope). His research interests include fractals and fractal structures, mechanics of materials, granular systems, geometrical packing, mathematical biology.

Dr Ciprian Coman (male) read theoretical mechanics at the University of Bucharest and was awarded a George Soros Fellowship to complete an MSc in mathematics at the University of Warwick. This was followed by PhD studies in Applied Mathematics at the University of Bath. Coman has been employed as a research scientist at Schlumberger Ltd. and the National Physical Laboratory. In addition to this, Ciprian has also held extended visiting appointments at several overseas universities (University of Western Australia, UC at Berkeley). His research interests include singular perturbation methods, solid mechanics and instabilities of elastic plates and shells.

4.1.c Relevant publications, products or services

"Imperfections in a two-dimensional hierarchical structure",
D. R.-Kirkhope, Y. Mao and R. Farr, *Physical Review E* **83**, 023201 (2014).

"Ultralight fractal structures from hollow tubes",
D. R.-Kirkhope, Y. Mao and R. Farr, *Physical Review Letters* **109**, 204301 (2012).

"Fractal space frames and metamaterials for high mechanical efficiency",
R. Farr and Y. Mao, *Europhysics Letters* **84**, 14001 (2008). [arXiv:1001.3940v2]

"Fractal design for an efficient shell strut under gentle compressive loading",
R. Farr, *Physical Review E* **76**, 056608 (2007). [arXiv:1001.3532v1]

"Fractal design for efficient brittle plates under gentle pressure loading".
R. Farr, *Physical Review E* **76** 046601 (2007). (arXiv:0912.3383v1).

4.1.d Relevant projects or activities

UK Ministry of Defence. Secured a €162,000 contract with the UK Ministry of Defence to manufacture and test a dozen fractal structures for possible further development.

4.2 Participant: Ramem SA

4.2.a Description of the legal entity

RAMEM SA (www.ramem.com) is a Madrid based company, headed by Emilio Ramiro. RAMEM is specialized in engineering and manufacturing of short series of parts and prototypes with high precision requirements and complex geometries. RAMEM has been established in 1958 to service the needs of clients who need complex technical expertise, typically for Aerospace Industries. RAMEM is member of SUMA aerospace (www.suma-aerospace.com/), company dedicated to the development and supply of on-board electro-mechanical equipment throughout the whole life-cycle of the product. RAMEM is has an active research line in post processing and precision finishing of parts produced by Additive Manufacturing (AM). RAMEM applies a portfolio of different post processing and precision finishing techniques to AM parts to make them fulfill the technical requirements regarding dimensions but also smoothing the roughness of the surfaces to increase the cracking resistance to fatigue.

RAMEM has designed and manufactured over 20,000 different equipment and components: Aircraft components and GSE/AGE for Airbus and Eurofighter; Instrumentation components for Industria de Turbo Propulsores (ITP) with Rolls Royce as final client; Repair work of flight parts for ITP and CESA; Prototypes and demonstrators for Indra, Lidax, INTA and Thales Alenia Space.
Additionally, RAMEM issues Certificates of materials, traceability, calibration, compliance and CE marking and Quality Certifications: UNE-EN 9100 and UNE-EN ISO 9001, registered in OASIS International Aerospace Quality Group, Industrial Security and Confidentiality agreements with its customers, Security Control Point, Environmental Management Systems and 'Health and Safety at Work' Systems.

4.2.b Key persons

Dr Silvia López Vidal (female) is the R&D Manager at RAMEM. She holds a PhD in Chemistry and has been extensively involved in the development of a prototype to characterize nanoparticles. She has published over 11 articles in relevant peer reviewed scientific journals and delivered over 10 presentations in scientific conferences and congresses. She is Principal Researcher and Project Leader in the Eurostars GANS project and Scientific Leader in the FP7, CS2 and H2020 projects in which RAMEM is involved.

Emilio Ramiro (male) is General Manager and Technical Director at RAMEM. He is a Mechanical and Aeronautical Engineer and has been working at RAMEM since 1984, participating in projects such as: manufacture of equipment for the maintenance of the Eurofighter engine, testing equipment for the International Space Station (ISS), primary mirror supports for the Gran Telescopio de Canarias (GRANTECAN). As Technical R&D Director he developed a wide range of scientific instruments such us High Resolution Ion Mobility Spectrometers or ElectroSpray Sources at RAMEM and began working in hybrid manufacturing and precision machining in 2008

Ignacio Zamora (male) is an Industrial Engineer and works in RAMEM as a Project Manager since 2008. During this time, he managed projects such as: design of an Acoustic Ion Mobility Spectrometer for R&D, manufacture of prototypes for the primary mirror supports of the E-ELT, design and manufacture of GSE's for AIRBUS, manufacture of an equipment for measurement of train axle alignment and manufacture of instrumentation rakes for Rolls-Royce. He also participated in a patent for R&D. components "Ion Mobility Spectrometer". He is currently working as Manufacturing Engineering Manager developing new and innovative manufacturing processes. He has also experience in topological optimization software for AM

4.2.c Relevant publications, products or services

RAMEM is member of the EMA4FLIGHT project granted by Clean Sky 2 to develop Electro Mechanical Actuators.
RAMEM is member of H2020 funded project HyProCell to develop a Manufacturing Cell including one stage of AM and another stage of Precision finishing.
RAMEM has collaborated with CESA in the manufacturing of the GRANTECAN1 and ELT2 prototype parts for telescopes.
RAMEM have received Spanish funding to collaborate in the project SELENA in which Aeronautic parts manufactured with AM will be qualified
RAMEM is leading ICARO project for the development of aeronautic flying parts with laser welding. 6.
RAMEM has manufactured the AIRBUS new generation stick for the A330 Multi Role Tanker Transport (MRTT) aerial refueling tanker aircraft.

4.2.d Relevant projects or activities

"AM in the Aeronautic sector", Book chapter in "COTEC Documents about technological Opportunities", E Ramiro, COTEC Foundation, ISBN: 978-84-92933-15-0 (2011).

"La fabricación aditiva para sectores industriales",
MA García García. Metalindustrial N2. p70 (2014).

"Characterization of a new mobility separation tool: HRIMS as Differential Mobility Analyzer",
M. Bouza, S. López-Vidal, J. Pisonero, N. Bordel, R. Pereiro and A. Sanz-Medel.Talanta, 130 400-407 (2014).

"Performance evaluation of a high-resolution parallel-plate differential mobility analyzer",
J. P. Santos, E. Hontañón, E. Ramiro, and M. Alonso. Atmos. Chem. Phys., 9, 2419–2429, (2009).

4.3 Participant: CNR, Italy

4.3.a Description of the legal entity

Consiglio Nazionale delle Ricerche (CNR)
The National Research Council of Italy (CNR: www.cnr.it) is the largest Italian public research organization, counting 109 institutes and more than 6000 researchers. Its mission is to carry out, promote, spread, transfer and improve research activities in the main sectors of knowledge and their applications for the scientific, technological, economic and social development. In particular it includes advanced research activities in modern physics and science of complexity, including heterogeneous and complex materials, to which it have devoted a big Institute: the Institute of Complex Systems (ISC). The institution will be involved in the project both in R&D activities and in the management of the project, through a multidisciplinary team the key elements of which comprises of Andrea Gabrielli and Antonio Scala who are all permanent researchers of ISC. Their work will be developed in collaboration with other scientists of other institutions associated to ISC, as Luciano Pietronero, Guido Caldarelli and Giulio Cimini. This group will work both in theoretical and computational aspects of the project work plan and will use both computer and structural facilities located both at the Institute of Complex Systems (ISC) of CNR and Department of Physics of "Sapienza" University of Rome.
Some of these scientists participated in the last years in related important studies, in the context of the FET STREP Project GROWTHCOM (Call FP7-ICT-2013-10, Grant Agreement n. 611272) and of the FET Proactive IP Project MULTIPLEX (Call FP7-ICT-2011-8, Grant Agreement n. 317532), about scientific,

technological and economic competitiveness of nations, and multi-layered social networks, which is part of the grounding of the project and in particular of WP1.

4.3.b Key persons

Andrea Gabrielli (male) (Theoretical physicist, Ph.D. 1998) will act mainly as Coordinator of the Project and of the WP1. He has a permanent research position at the Institute of Complex Systems (ISC) of Italian CNR. In the last years he developed different studies ranging from complex network applications to neural and socio-economic systems. In the past he studied the application of complex systems and fractal concepts to different domains including scale-invariant growth models and cosmology. He has a solid expertise in statistical physics of complex systems, fractal growth phenomena, stochastic processes and complex network theory. He enjoyed different post-doc positions at the Ecole Polytechnique (Paliseau, France), at the Italian Institute for the Physics of Condensed Matter (INFM) and at the Centro Studi e Ricerche "Enrico Fermi" in Rome. He has now also a Visiting Professor position at Institute for Advanced Studies (IMT) of Lucca, at the Physics Department of the Boston University (MA, USA) and research Fellow at the London Institute for Mathematical Sciences (LIMS). He is author of around 100 scientific publications on peer reviewing international journals. He has also published one scientific book of statistical physics and fractal geometry to cosmological problems (Springer, 2004) and a chapter for a book on complex networks (Cambridge Univ. Press, 2010). Web-page: http://pil.phys.uniroma1.it/~andrea.

4.3.c Relevant publications, products or services

“Statistical Physics for Cosmic Structures”,
A. Gabrielli, F. Sylos Labini, M. Joyce, L. Pietronero, Springer (Berlin – New York, 2005).

“Self-stabilized fractality of seacoasts through damped erosion”,
B. Sapoval, A. Baldassarri, A. Gabrielli, Physical Review Letters 93 (9), 098501 (2004).

“Percolation in real wildfires”,
G. Caldarelli, R. Frondoni, A. Gabrielli, et al., Europhysics Letters 56 (4), 510 (2001).

“Spatio-temporal anomalous diffusion in heterogeneous media by nuclear magnetic resonance”,
M. Palombo, A. Gabrielli, S. De Santis, C. Cametti, G. Ruocco, S, Capuani, The Journal of Chemical Physics 135 (3), 034504 (2011).

“Small-world networks and the conformation space of a short lattice polymer chain”,
A. Scala, L.A. Amaral, M. Barthélémy, Europhysics Letters 55, 594 (2001).

4.3.d Relevant projects or activities

CrisisLab: “” (2012 - present; CNR Projects Of National Interest funded by Italian Government).

European Project GROWTHCOM: “Growth and innovation policy modelling - Applying next generation tools, data and Economic Complexity ideas” (2013 - present; FP7-ICT-2013-10 call, Grant Agreement 611272).

European Project MULTIPLEX: “Foundational Research on MULTIlevel comPLEX networks and systems” (2012 - present; FP7 FET-ICT IP project, Grant Agreement 317532).

European Project FOC II: “Forecasting Financial Crises’ II’ (2012 - 2013; FP7 FET-Open Project, Grant Agreement: 255987).

European Project “Fractal Structures and Self-organization" (1997 - 2002; TMR program of the EEC, contract number: FMRXCT980183).

4.4 Participant: PRODINTEC

4.4.a Description of the legal entity

PRODINTEC is an industry-driven multisectorial Technology Center created to boost the competitiveness of European companies by applying research and development activities to either product designs or manufacturing processes. PRODINTEC is specialized on supporting companies in the whole value chain for Additive Manufacturing, providing complete innovative solutions from 3D-scanning, to series production including the use of advanced software for Additive Manufacturing, quality control and post-processing. PRODINTEC has facilities with a surface of 5.000 m2 divided into workshops and laboratories, offices, meeting, training and conference rooms.
The capabilities of PRODINTEC have made of it the leader in Spain in R&D projects and innovation services in Additive Manufacturing, performing more than 2.000 innovation services and 30 R&D projects in Additive Manufacturing in several sectors and applications, such as electronic equipment enclosures, medical implants, aerospace, automotive parts and conformal cooling moulds and micro-moulds. Since January 2012, PRODINTEC is a certified e-manufacturing partner of EOS, the world-leading producer of laser-sintering systems.
Moreover, the Center is an active member of different European Technology Platforms related to manufacturing such as MANUFUTURE and micro and nano technologies as MINAM and NANOfutures. Prodintec has wide experience in European research programmes as, for instance, FP, EUREKA, Era-Nets and INTERREG where it works in close collaboration with industrial partners, research institutes and public administration around Europe.
PRODINTEC has the largest additive manufacturing facilities in number, capacity and range of materials in Spain (and possibly in Europe).

4.4.b Key persons

Dr. David Gonzalez, Chemist and PhD in the Materials Science (male), he has more than 10 years' experience as researcher in academic and industrial contexts in entities such as CSIC (Spain), Manchester Material Science Centre and Institute of Food Research (UK) and VTT and Technical University of Technology (Finland). Robust experience in management of R&D projects at national and international level, including coordination of FP7 projects. Innovation expert for international institutions in Spain, Europe and LATAM countries. Author of more than 50 articles related to research and innovation in the abovementioned areas of knowledge. Co-owner of 2 patents in nanotechnology. Today he is Director of the Advanced Manufacturing Department at PRODINTEC.

Mr. M. Antonio García is Mechanical Engineer (male), and has obtained the Master of Advanced Studies (2009). In 2007 he joined PRODINTEC and was in charge of setting up the Additive Manufacturing Technologies Group, specialized in Laser Sintering both in metal and in polymers. He has participated in several R&D projects related to Additive Manufacturing at national and international level. He has been very active in promotion and dissemination of the benefits and success cases of additive technologies at national and European level both with presentations and articles (eg. contribution to the book “Additive layer manufacturing”). Antonio is also inventor of some patents in the field of AM (eg. EP2345390 – Procedure for the manufacture and implant of sponge material of governable density”). He is currently head of the Unit of Manufacturing Technologies at Fundación PRODINTEC.

Mr. Juan Carlos Piquero PhD student (male), received the B.S. degree in Geology (2003) from the University of Oviedo, Spain, he is also Geologic Engineer from the University of Oviedo (2006) and MBA from IMF Business School (2013), currently he is a PhD student. He has more than 8 year of professional experience on R&D activities. Juan Carlos has worked as researcher in the University of Oviedo (two years) and he worked in Advanced Material Group of ACCIONA Infraestructuras (Madrid). During his three years period in ACCIONA, he was Project Manager of several national and international R&D projects. Since 2011, Juan Carlos is Project Manager in PRODINTEC as part of Innovation and Project Management Dimension. In 2014 he is part of advanced manufacturing dimension as project manager and technical responsible for several projects related to the application of additive manufacturing technologies.

Mr. Taodan Kaptan Abood**:** BSc in Aerospace Engineering minor in Aircrafts and MSc in Mechanical Engineering and Transportation. Around 3 years' experience in several companies as Aeronautical Engineer such as Spanish Air force as Maintenance and Structure Engineer, Indra Sistemas S.A as Aeronautical Engineer. In 2016 he is part of advanced manufacturing dimension as Aeronautical Engineer.

4.4.c Up to five relevant publications, products or services

PRODINTEC has participated providing technological services, by means of Advanced Manufacturing techniques, within the frame of the following projects accomplished by main players in the aerospace/defense sector:

Research on the implementation of additive manufacturing technologies in the aerospace sector - Aciturri Additive Manufacturing, S.L

Materials and advanced manufacturing technologies for the next generation of high-speed turbines (FUTURALVE) - Mizar Additive Manufacturing S.L.U

Safer and reconfigurable electrical systems towards more efficient plane construction through reduction of pilot load (SELENA) - Cesa and Ramem

Economic evaluation of additive manufacturing technology - Aciturri Additive Manufacturing S.L
Design and manufacture of metal Aeronautical com ponents by Selective Láser Maelting(SLM) - Addifly - Aernnova

4.4.d Up to five relevant projects or activities

PRINTCR3DIT**:** 'Process Intensification through Adaptable Catalytic Reactors made by 3D Printing' H2020, European Commission (2015-2018).
ECLIPSE "Design and manufacturing of novel light-weight structures for aeronautic sector". Spanish Ministry of Economy and Competitiveness and private investment (2013).
SILENCIO "Implementation of additive manufacturing technologies in the value chain of aeronautic sector". Spanish Ministry of Economy and Competitiveness and private investment (2013).
CREABLE "Novel e-platform for promoting business around additive manufacturing technologies"; Regional Government and private investment.
INTELIMPLANT "Design and manufacturing of bespoke medical implants by laser sintering". Spanish Ministry of Economy and Competitiveness and private investment (2010).

TRANSRM “Implementation of additive manufacturing technologies in the industrial Spanish Ministry of Economy and Competitiveness and private investment (2010).

4.5 Participant: London Institute, UK

4.5.a Description of the legal entity

The London Institute for Mathematical Sciences is a private physics and mathematics research centre based in London with expertise in statistical mechanics, fractals and complex systems. LIMS attracts the best scientists from inside and outside the UK and gives them the freedom to pursue their ideas without constraints; there are no lecturing or administrative duties. LIMS provides generous support so that its scientists can focus entirely on their research. While LIMS’ faculty is small, it is consistently distinguished, including two Fellows of the Royal Society. StructX has work with the London Institute for the last four years on fractal designs with Fink and a junior scientist.

Recently LIMS opened a new five-floor research centre in the heart of Mayfair, London, specifically designed for interdisciplinary research between theorists without the usual departmental barriers. The research space is made up of rooms on all length scales, where theorists can work singly or in groups. At the top floor of the Institute are en suite guest rooms where visiting scientists and PIs can stay. LIMS has invested in top-end Apple Mac computing facilities for all its Fellows and junior scientists.

4.5.b Key persons

Dr Thomas Fink studied physics at Caltech, winning the Fisher Prize for top physicist, and did a PhD at the Cavendish Laboratory, Cambridge with Robin Ball. He was a Junior Fellow at Caius College, Cambridge, and a postdoc at Ecole Normale Superieure with Bernard Derrida. He is currently a Charge de Recherche in physics in the French CNRS and the Director of the London Institute for Mathematical Sciences. Fink has written popular science books with sales of 1/3 million. His research interests include discrete dynamics, fractal structures, statistical mechanics, graph theory, evolvability, mathematical biology.

4.5.c Relevant publications, products or services

T Fink, Fractal branching columns: from Gaudi to ultra-strong, light structures, manuscript.
T Fink, M Reeves, R Farr, Dynamics of rapid innovation (http://arxiv.org/abs/1608.01900), submitted to Science.
T Reeves,..., T Fink, Eigenvalues of neutral networks, Discrete Mathematics, 339, 1283.
R Farr, J Harer and T Fink, Easily repairable networks, Physical Review Letters 113, 13.
S Ahnert et al., Self-assembly, modularity and physical complexity, Physical Review E 82, 026117.

4.5.d Relevant projects or activities

Adaptive networks. Led a $1.05m research project funded by the U.S. Department of Defense for designing networks capable of self-healing and adapting, which involved managing a team of 5-8.

Dynamics of rapid technological innovation. Led a $250,000 research and development research project funded by the Boston Consulting Group to develop a theoretical foundation for what drives innovation in companies.

DARPA FunBio. Was a co-investigator in a research grant from the Defense Advanced Research Projects Agency to understanding the dynamics of evolvability.

4.6 Third parties involved in the project

Do the participants plan to subcontract tasks.	No
Do the participants envisage that part of its work is performed by linked 3rd parties.	No
Do the participants envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the general model grant agreement)	No

5 Ethics and security

5.1 Ethics

There are no ethics issues involved.

5.2 Security

Please indicate if your project will involve:

1. Activities or results raising security issues	No
2. 'EU-classified information' as background or results	No

Extra notes to ourselves (not part of application)

In determining the appropriate set of partners for our consortium, we considered several of the leading additive manufacturing teams across Europe and member countries: the EPSRC National Centre for Additive Manufacturing at Nottingham University, the for-profit spinoff Added Scientific (whom StructX has worked with before), the Israeli place, the two Swedish places, the other Spanish place.

PARTICIPANT PORTAL E-RECEIPT

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