



*Foresight*

# *Nano to Macro Integral Manufacturing*

Targeted scenario N°12

**Glimpses of the future  
from the BOHEMIA study**



## ***Nano to Macro Integral Manufacturing - Targeted scenario N°12***

European Commission  
Directorate-General for Research and Innovation  
Directorate A Policy Development and Coordination  
Unit A.3 Horizon 2020 Policy and Foresight  
Contact Nikolaos Kastrinos  
E-mail [nikolaos.kastrinos@ec.europa.eu](mailto:nikolaos.kastrinos@ec.europa.eu)  
[RTD-PUBLICATIONS@ec.europa.eu](mailto:RTD-PUBLICATIONS@ec.europa.eu)  
European Commission  
B-1049 Brussels

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EUROPEAN COMMISSION

***Nano to Macro Integral  
Manufacturing***  
**Targeted scenario N°12**

***Glimpses of the future  
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## **About BOHEMIA**

*BOHEMIA is a foresight study (contract N° Contract PP-03021-2015) designed specifically to support the preparation of the next framework programme.*

*The study put forward policy recommendations for the next framework programme, based on a foresight processes involving scenario development, a Delphi survey and an online consultation.*

*As part of its recommendations, the study identified 19 likely future scenarios with disruptive implications and associated priority directions for EU research and innovation.*

*The full range of the results of the study is available at <https://ec.europa.eu/research/foresight>*

Targeted scenario N° 12  
***Nano-to-Macro Integral Manufacturing***

**Summary**

Mature 3D printing technologies have become one of the main modes of production of finished goods. Aided by advances in nanotechnology, additive manufacturing has entered many high-value added markets. Changes in product design have rendered it possible for whole products to be made with fewer or no intermediate goods. As a result, traditional global value chains have been disrupted in terms of both geographic span and density.

**UN Sustainable Development Goals (SDGs) most relevant to this scenario:**



## **The scenario**

It is 2040. Mature 3D printing has become one of the main modes of production of finished goods. Not only have additive manufacturing technologies expanded in variety and efficiency, but they have extended to previously unconquered industrial sectors through radical advances in nanomaterials. The latter have enabled the “printing” of much more resilient objects, much cheaper metals, alloys and transparent glass. Spurred by 3D printing, manufacturing based on nanomaterials has also broken into new, high-added value market segments: stronger, lighter, more conductive and more flexible nano-structures have shaken up industries from aerospace and medicine to electronics and energy.

3D printing technologies now routinely cover a large spectrum of resolutions. These extend from the nanoscale (ultrasonic 3D print works with shapes and sizes varying “from the sub-millimetre to the millimetre range”) up to very large objects, such as buildings. Indeed, the ability to scale up nano-structures to macro level via 3D printing has revolutionized the engineering of materials.

As a result, many industrial value chains have compressed in both geographic span and density, or have been substantially upset. The ‘DIY’, ‘home-made’ or ‘short-run’ approach to manufacturing has lowered the barrier of entry for local entrepreneurs and led to a revitalization of small shops. Major shifts in product design philosophy, such as part consolidation, have now rendered it possible for numerous products to be made with much fewer intermediate goods. Final products can now be produced locally and on demand, reducing the need for high-volume production facilities, transportation, and warehousing. Emphasis is now on the adequate supply of high-quality materials and on services for fast customization. There is a financial premium on responsiveness to individual consumer preferences. Self-healing, shape-shifting and other 'smart' materials are growing markets.

## **Relevance for Europe**

The inevitable rise of additive manufacturing throughout the world will lead to a fundamental reconfiguration of specializations among countries. For some it is an opportunity to ‘re-shore’ industrial production. For others it is an opportunity to exploit really advanced knowledge and technology at a global scale. All in all, the economic interest is enormous. Three industries (aerospace, medical and dental) are forecasted to become leaders in advanced materials markets with automotive industries growing significantly. Asian companies will soon assert greater influence.<sup>1</sup> So is the societal and political interest. Material properties are very important in everything, from infrastructure, through military equipment to the smaller sensor and circuit. Europe could play a leading role or a peripheral one: the challenge is to compete effectively in knowledge production and to capitalize on knowledge assets throughout industry.

## **Contribution towards the UN Sustainable Development Goals (SDGs)**

The rise of integral manufacturing is primarily relevant to the industry related SDG 9 (in particular 9.4 on “increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes”, and 9.5 on enhancing “scientific research, upgrade the technological capabilities of industrial sectors in all countries”). However, it is also potentially important for “responsible consumption and production” (SDG 11) and for the environment-related SDGs.

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<sup>1</sup><https://www.bcg.com/publications/2017/lean-manufacturing-industry-4.0-get-ready-for-industrialized-additive-manufacturing.aspx>

## Implications for EU Policy

Broad questions of industry- and trade-related policy arise, especially if global value chains (as we know them) are to be substantially affected or disrupted. Transportation and logistics related policy will be crucial. The consequences of additive manufacturing for employment across industrial sectors need to be carefully examined.

Intellectual property and design rights are directly relevant, in particular issues of property over blueprints and counterfeit products, as additive production technologies become accessible and expand to increasingly more industries. Original schematics may be pirated and circulated widely, and 'fake blueprints' may invade the counterfeit additive manufacturing market.

Questions of (cyber-) security will also be paramount, as additive manufacturing processes can be hacked to generate flaws in products.<sup>2</sup> Even small, undetectable changes in products objects in larger products may lead to catastrophic failure.

While there is some promise in additive manufacturing as far as its environmental footprint is concerned (e.g., major reduction in transportation costs), its impact on the environment remains an open question. The evolution of the relevant technologies will depend substantially on environmental policy constraints (such as the use of energy or waste policy).

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### Future Directions for EU R&I policy recommended by the public consultation

- **Understanding the impact of 3D printing on individual health and safety and on the environment, across various industries**
  - **Improvements in nano-to-macro 3D printing technologies**
  - **Piloting various applications for the local, decentralised production of 3D-printed objects**
  - **Improving technologies for nano-based and functional materials with an eye to scaling them up to mass-production**
  - **New designs for 3D-printed objects that emphasize their disposability and recycling**
  - **Inquiries into and experimenting with frugal (low-cost) innovation enabled by 3D printing**
  - **Understanding and improving quality control in industries which may become reliant on 3D-printing (e.g., automotive)**
  - **Studying and developing new materials that can be used in or adapted to integral manufacturing technologies**
  - **Research on the impact of additive manufacturing on employment in various industries.**
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<sup>2</sup> Chris Wiltz, "3D Printing Has an Urgent Need for Cybersecurity", Design News, March 17, 2017 (<https://www.designnews.com/3d-printing/3d-printing-has-urgent-need-cybersecurity/42281071756489>).

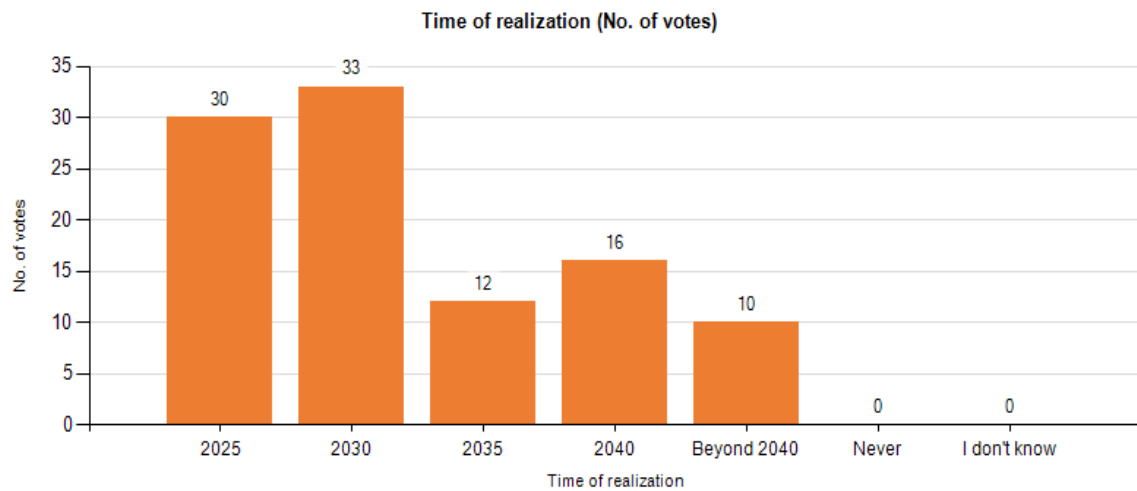
## **Annex: Relevant Data from the Delphi Survey**

The Delphi survey of the BOHEMIA study asked experts about the time of realization of 143 statements about the future, and about the relevance of Research and Innovation for that realization, or about the relevance of the realization for Research and Innovation policy. The experts were asked to justify their judgements with arguments. The whole data set has been published and can be found at: <https://ec.europa.eu/research/foresight>

This annex includes the parts of the data set that are relevant to this scenario.

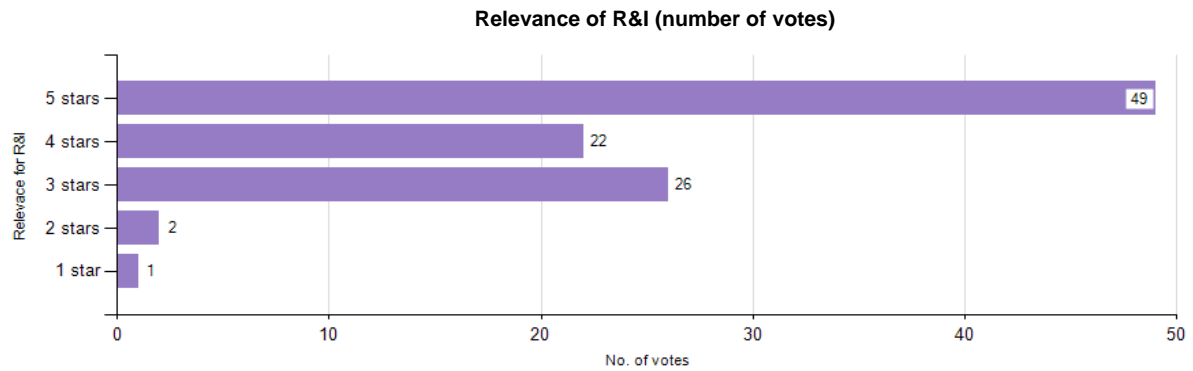


**Adaptive materials and surfaces that are able to change their characteristics according to user requirements appear in consumer applications**



**Number of respondents:** 101

<b>Arguments regarding the time of realization</b>	<b>No. of votes</b>
There is already a lot of research going on, e.g. the development of interactive functional materials and smart surfaces, as well as embedded micro systems and functional films for adaptive plastics.	92
Applications of nano materials are still quite niche.	24
Adhesive materials and surfaces are still a big challenge.	24
Smart materials can be designed for military advantage as well as competitive advantage in consumer products, e.g., smart windows that adapt to changing light intensity.	11
Insights will tell us how smart product functionalities can be realized through specific characteristics integrated in the surface (at micro or nano scale, by different production technologies).	10
Smart surfaces will be produced for personalized medicine approaches for medical devices.	6
Strong incentives to deploy smart materials that offer competitive advantage will drive rapid market introduction.	6

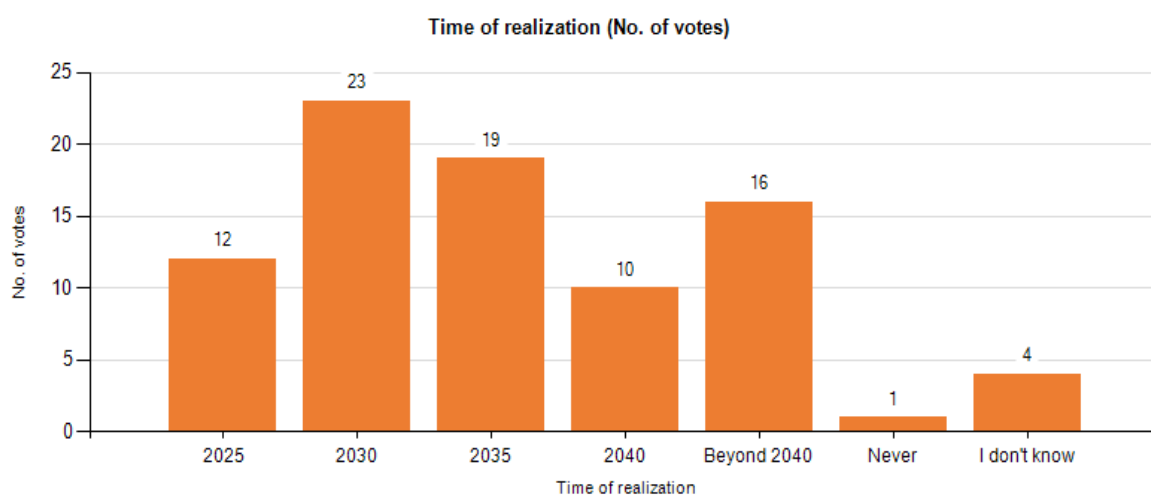


**Average:** 4.16

**Dispersion:** 0.89

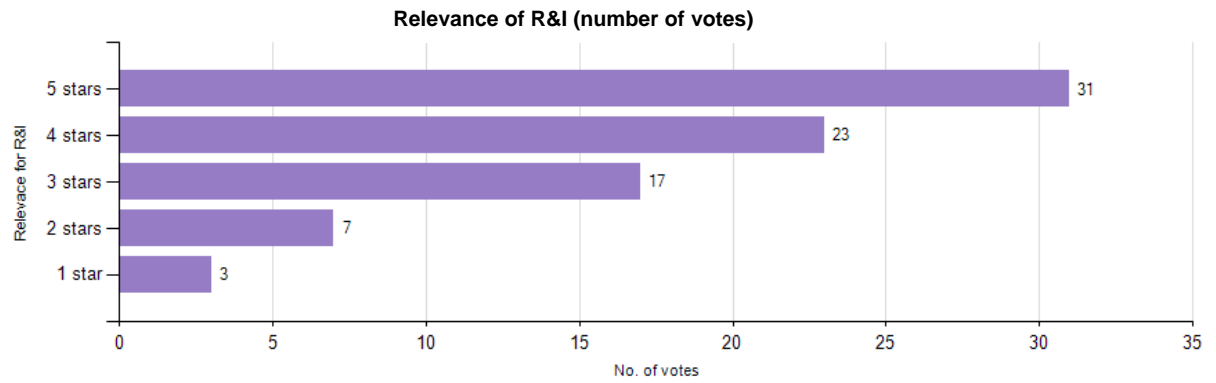
Arguments regarding the relevance of R&I	No. of votes
Development of interactive functional materials and smart surfaces as well as of embedded micro systems and functional films for adaptive plastics is needed for a significant contribution to biomimetics, self-regulating reinforcement, and self-repairing.	87
This also depends on the degree to which the consumer is prepared or willing to deal with such materials (hence, market-dependent and not only R&I-dependent)	27
The understanding of the user and his/her requirements is very difficult and needs very specific research.	18
More in-depth understanding is required between the functionalities requested in consumer applications and the characteristics of adaptive materials and surfaces that enable to realise them	15
Smart materials will be developed where they give competitive advantage to products with features that better meet consumer needs than non-adaptive.	14
Deeper knowledge of surface interaction with human tissue will be required to design personalized medical devices.	6
The important applications for adaptive surfaces are primarily architectural (for passive heating, cooling, and lighting), not consumer products.	5
Adaptive materials can include functionality addressing systemic needs not just features, e.g. enable more effective recycling with self-destructing drink bottle caps for empty bottles.	5

## Self-healing, shape-shifting materials reacting to light and heat are applied for the first time in large-scale construction in the EU



**Number of respondents:** 83

<b>Arguments regarding the time of realization</b>	<b>No. of votes</b>
The cost factor will prevent large-scale adoption for the short- and medium-term future.	55
Even the latest advances remain mostly laboratory stuff with few proven commercial prototypes.	38
The construction area is highly scattered and conservative market. All players (architects, builders, building owners, ...) need to be informed about the advantages of new building materials.	17
University of California and University of Colorado scientists developed in 2016 a transparent rubbery material that can be stretched up to 50 times its original size, is conductive, and self-heals mechanical damage.	12
Thermochromic windows (darkening when warm) have been commercially available for over a decade already.	12
Chinese construction product innovation may drive change as Chinese construction firms enter EU markets with use of adaptive materials enabling market entry against entrenched competition.	4
There is already a self-healing concrete, light reacting paints and other materials following.	4
Such materials need to respond to real customer/consumer needs	1
Chinese construction market, the largest in the world, facing increasing costs and competitive pressure driving innovation.	1

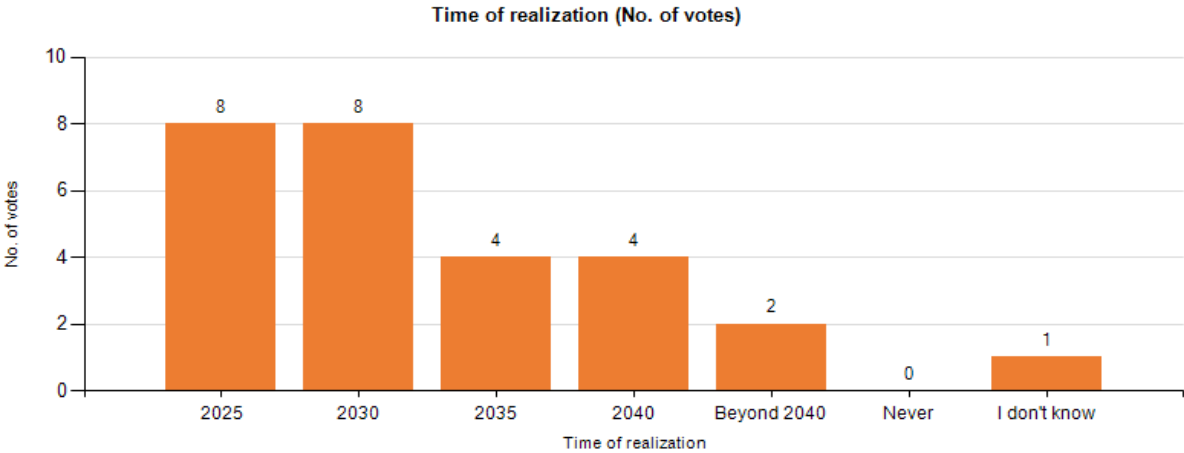


**Average:** 3.89

**Dispersion:** 1.25

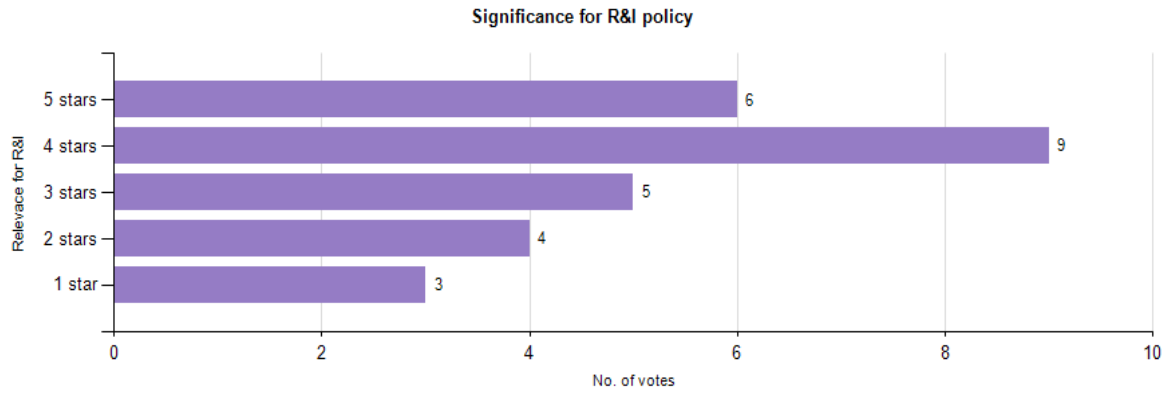
<b>Arguments regarding the relevance of R&amp;I</b>	<b>No. of votes</b>
Develop close-to-market prototypes based on self-healing properties of materials.	58
Improve the cost-efficiency of self-healing materials.	55
There is a need for demonstrator buildings to show the advantages of new construction materials.	26
R&I of adaptive materials is important, but the most important adaptations are not shape, they are transmission / reflection of heat and light.	9
Bridges and similar high use construction that requires adaptation to expansion, heat and cold can benefit from self-healing adaptive materials.	3
Building systems that can enable vertical agriculture, lower cost energy and air conditioning more effective water use will have competitive advantage	1

**The work of consumers (original designs, customization), along with the emergence of 3D printing redefines manufacturing industries**



**Number of respondents:** 27

Arguments for time of realization	No. of votes
3D printing allows consumers to print (produce) their own products.	16
3D printing is already beginning to redefine the after-sales "servicing" sector.	14
3D printing counters globalisation as production on the spot becomes cheaper than traditional production, in addition to being more personalised.	12
Co-creation is becoming the dominating paradigm, this means that users and producers are more and more the same persons and jointly produce something.	12
It is unlikely that 3D printers would do away with the advantages of large assemblies of industrial robots any time soon.	7
3D printers will redefine the way design functions, and may lead to the emergence of a strong design sector.	4
Co-creation and 3D-printing do not re-define anything. They just complement and augment what has been the status quo for some time now.	3



**Average:** 3.41

**Dispersion:** 1.63

<b>Arguments regarding the significance for R&amp;I policy</b>	<b>No. of votes</b>
R&I policy can foster the new industries of 3D printing.	17
Ownership of open innovation needs clarifications also in case of 3D printing.	10
Citizen and consumer policy gives the power back to the citizens.	6
EU R&I policy will become more efficient as links between Research and Innovation are likely to be strengthened by a wide spread of 3D printing.	5
Research into developing the educational system to deliver the needed MINT, engineering and design skills on a broad basis is needed.	5
EU R&I policy should focus on the understanding of 3D printing within population. A 3D knowledge divide would lead to increasing inequalities, reflected in income inequalities and social unrest.	5
Considering the limitations of 3D-printing in terms of materials used, the logistic and marketing should precede learned guesses about the fantastic possibilities that it eill/might open.	3

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*Studies and reports*

