Loughborough Innovative Manufacturing and Construction Research Centre (IMCRC)

Key Data	
Time Period	**10 Years total** 1st October 2001-30th September 2011
Total Value of EPSRC Grant	**£32.0m total**
Other Funding *(Direct leverage of additional research funding specific to IMRC)*	**£34.4m total** (108% of EPSRC funding) • Research Councils, non-IMRC (£7.2m) • UK public sector, non-Research Council (£2.2m) • UK private sector (£19.0m) • Overseas (£6.0m)
Projects	214 projects funded to date
Current Staff	**145 total -** 38 Academic staff, and 107 Post-doctoral researchers
PhD Students	198 PhDs completed to date + 55 current PhD students *(funded by IMRC grant or supervised by staff involved in IMRC)*
IMCRC journal publications	469
Patents granted	5
Key Sectors of Focus	Regenerative medicine, Electronics manufacturing, Additive manufacturing, Intelligent automation, Sports technology, Sustainable manufacturing, Construction
Current Research Themes/ Specialisms	• Customised Products • Healthy & Secure Future • High Value Assets • Next Generation Technologies • Transforming Organisations
Examples of key economic impacts	**1. Informing the Build Design Process at Manchester City Council** – A method developed at the IMCRC has been used to help inform the design process for new primary schools in Manchester worth around £36 million since 2005/2006 **2. Development of a new automated cell culture system** – Total revenues of £21.5 million up to January 2011 **3. Development of a new powder-based inhaler** – A 1-2% share of this market would equate to annual revenues of £33 million-£65 million **4. Development of the Reebok Deck and i-Play** – Combined revenues of circa. £8.5 million to date **5. Reducing emissions in the aerospace sector** – Indicative estimate of £60 million in carbon savings for a single aircraft over a 30 year lifespan **6. Cost savings to the automotive sector** – Estimated cost savings of £100 million if the business driven automation techniques are applied to the engine programmes being run by Ford at any one time.
Key value added aspects demonstrated by the IMCRC	• Providing continuity to research themes • Multi-disciplinary working – both internally and externally • Enhancing existing industrial networks and supporting the development of new links with the private sector • Providing a more strategic focus for research

Overview of the Loughborough IMCRC

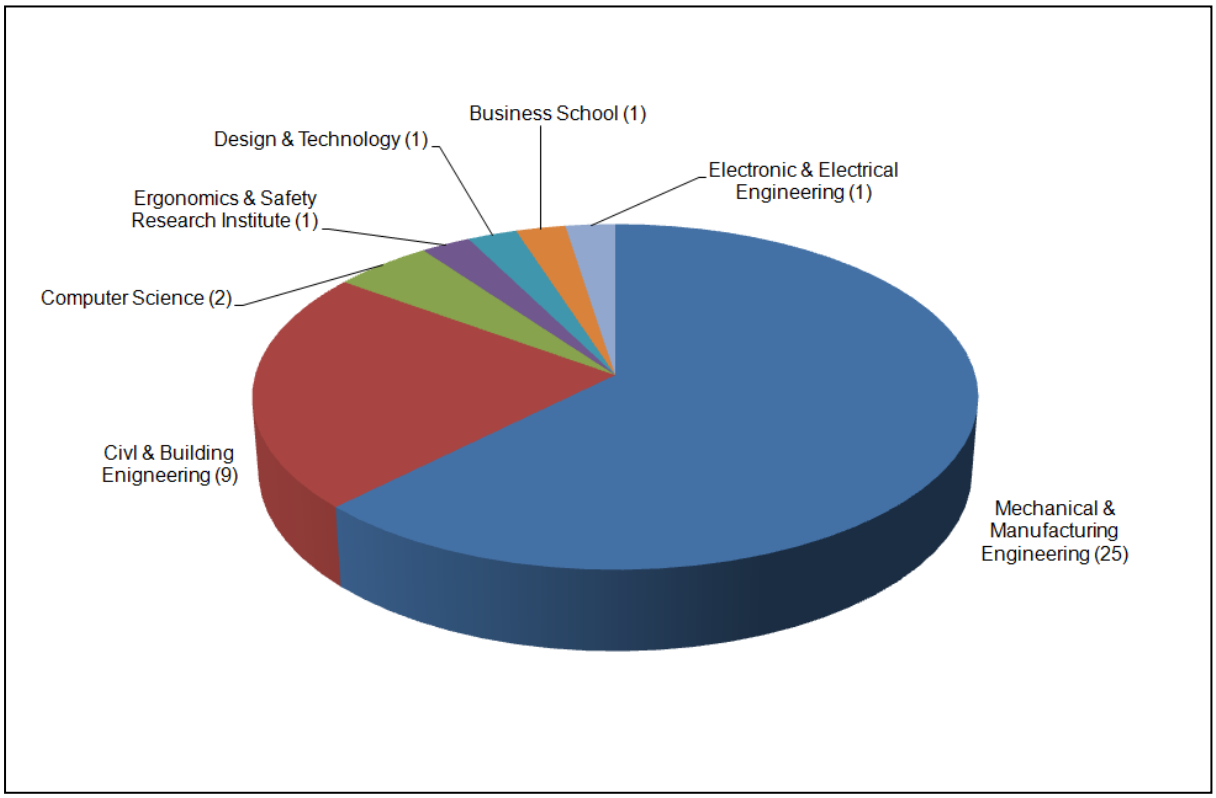
Loughborough IMCRC is the largest of the IMRCs, in terms of number of academics, amount of funding and breadth of work undertaken. It covers a range of research issues from design, processes and materials, to business and management; and includes manufacturing, construction, systems engineering and computer science.

It has a portfolio of over 200 projects, 46 of which are ongoing. Nearly 40 Loughborough University academic staff contribute to the research which has involved more than 200 researchers, 107 of whom are engaged on current projects. The IMCRC has been involved in all four 'Grand Challenge' projects and led the Regenerative Medicine Challenge.

The academics involved with the IMCRC belong to a variety of departments as shown in Figure 1. The highest number of academics (25) are from the Mechanical and Manufacturing Engineering department.

Loughborough has a long history of working with industry and many of the IMCRC projects relate to improving existing business competitiveness or new business creation. However, other elements of the research programme are playing a key role in the public arena. For example, Professor Simon Austin's work on identifying value in design is being used in a number of different areas, and elements of the research have been used by Manchester City Council as part of developing an integrated approach to the design process for new schools.

Figure 1: Number of Academic Staff at Loughborough IMCRC by Department



Following EPSRC visiting panels and internal reviews, the Centre structure has developed from independent research groups into three Research Units (Construction, Manufacturing and Product Customer Interface) working across five Research Themes. Each of these form a defined group of academics. Each Research Unit is led by a senior academic and the five Research Themes are led by an academic who is responsible for the strategy and direction of the theme. Academic staff are associated with a Research Unit but can work in any of the research themes. Individual academics

are responsible for managing projects on which they are Principal Investigator (PI) and report to the Research Manager.

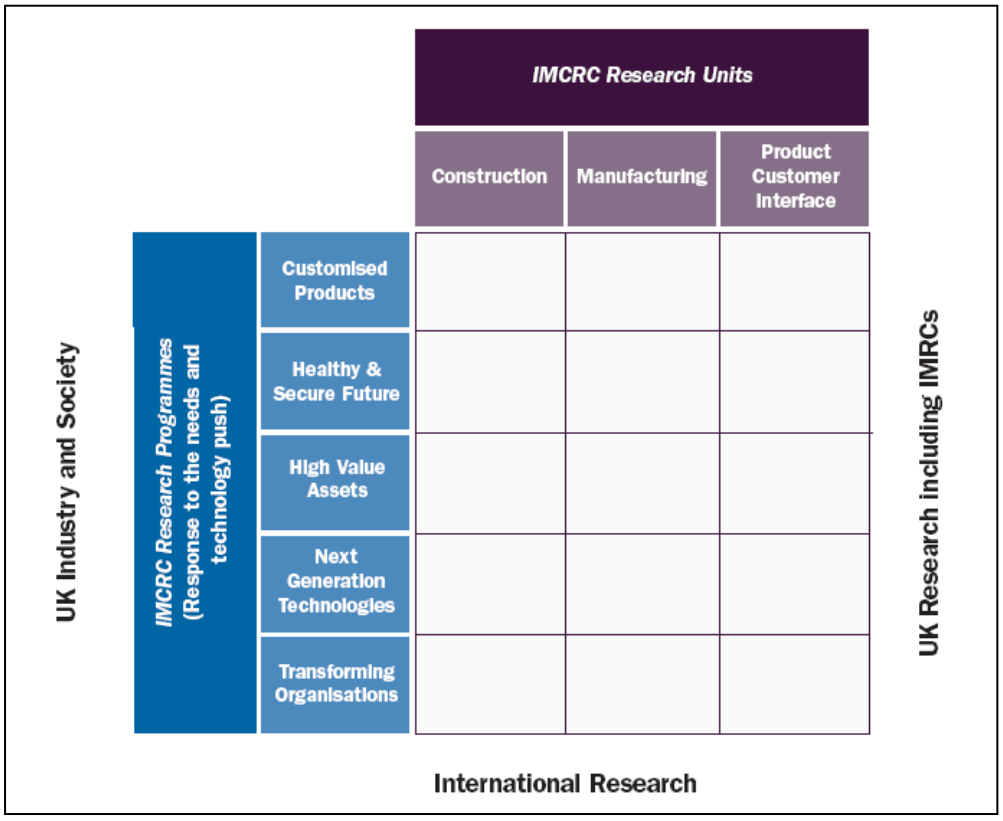
IMCRC Research Strategy

When the IMCRC was established in 2001, existing EPSRC funded projects were incorporated into the IMCRC portfolio. As the Centre funding was based on previous grants awarded to academics (that worked in groups), and because of the ongoing projects, it was decided to assign each group a notional five year budget proportional to past funding. Group budgets were top-sliced to provide funding for 'Strategic' projects and to cover management costs. Research groups involved were:

- Construction human factors
- Construction informatics
- Construction process
- Innovative digital manufacturing
- Loughborough PRIME Faraday
- Manufacturing automation
- Manufacturing organisation
- Sports technology
- Rapid manufacturing.

In 2003 the Centre was reviewed by an EPSRC panel which who endorsed the quality of research being undertaken. In 2004 an independent review of the Centre assessed the operational procedures and research quality. A number of key changes took place as a result of this, including developing a new structure and research themes for the period 2006-2011. The IMCRC has subsequently undertaken research within five broad areas and Figure 2 summarises the structure, with further detail on each research theme provided in the following section.

Figure 2: Loughborough IMCRC Research Units and Themes



- **Customised Products:** Seeking to make products that suit the requirements of customers at a cost similar to mass-produced goods.
- **Health & Secure Future:** Aiming to provide enhanced environments and products to improve safety and security, in addition to promoting healthier lifestyles.
- **High Value Assets:** The IMCRC is delivering the tools, techniques and designs to maximise the utility and return from assets such as military platforms, production systems and major buildings whilst ensuring that companies, governments and the general public gain maximum benefit from the investments needed to produce these products.
- **Next Generation Technologies:** Providing industry and commerce with a radical set of technologies based on new materials, processes, and information systems which will transform existing practices and deliver innovative products to the customer.
- **Transforming Organisations:** Addresses learning and knowledge management, strategic management and leadership, and business models for networked organisations so that they can easily adapt to the changing business environment.

The table below provides a breakdown of projects and funding by research theme. All projects have been grouped into at least one of the current five research themes, rather than the research groups that were used when the Centre was established. There are a number of projects that incorporate aspects of more than one theme, therefore projects may be double-counted. The table shows that the 'Next Generation Technologies' theme accounts for the highest level of funding (£22 million). In addition, the research themes are spread across each of the three research areas of design, technology and management – and sometimes projects fall into more than one category (hence the categories do not total to 100%).

Theme	Number of Projects (To Date)	EPSRC Funding (£) (Budget Allocation)[1]	Design	Technology	Management
Customised Products	65	£6.2m	69%	72%	48%
Healthy & Secure Future	32	£6.9m	66%	63%	69%
High Value Assets	46	£3.7m	43%	61%	67%
Next Generation Technologies	156	£22.0m	53%	75%	52%
Transforming Organisations	69	£8.0m	33%	22%	91%[2]

IMCRC Programme Management

Looking at the current structure of the IMCRC, the Executive Board manages the operational activities such as approval of strategy and funding allocations. It meets approximately once per month to manage the overall activities of the Centre. There is also a Steering Group which provides advice on research direction and prioritisation.

[1] Includes IMCRC funding, plus an additional £15.1 million EPSRC funding.

[2] These apportionments are approximate and were made following a review of the IMCRC project portfolio

The Steering Group meets at least twice per year to advise on major activities and strategy and consists of external members and some members of the Executive Board. The aim of the Executive Board and Steering Group is to provide a framework of governance that:

- Determines the operational processes
- Ensures transparency of processes
- Ensures that sanctions are imposed through normal University procedures if required.

The IMCRC also makes use of an International Review Panel to assess the quality and impact of the research and to advise on management processes. Institutions represented on this Panel include: Massachusetts Institute of Technology (MIT); University of Texas at Austin; Galway University; and Katholieke Universiteit Leuven.

On a day-to-day basis, there are three people who take on the main responsibility for managing the IMCRC:

- The Centre Director – Professor Andrew Baldwin
- The Research Manager – Dr James Bishop
- The Centre Coordinator – Mal Rooney.

The Director is responsible for all activities of the IMCRC. Major activities include oversight of the proposal process, project reviews and the international quality review of the research portfolio. The Research Manager ensures that individual projects perform as expected, which includes: attending project review meetings; organising the project selection process; and collating reports from projects. Both the Centre Director and Research Manager sit on the Executive Board and Steering Group.

The Centre Coordinator provides support for the Director and Research Manager and is involved in organising IMCRC Centre activities such as dissemination events and public engagement activities.

Project proposals for IMCRC funding are evaluated by three external reviewers. The Principal Investigator produces a one page response to the comments of the reviewers. An internal panel then reviews the proposals taking into consideration the comments of the external reviewers and the Principal Investigator's (PIs) response. In order for a project to be funded, it must be seen to be either Internationally Competitive or Internationally Leading. For some calls such as those for Integration Projects there was an additional stage in the selection process in which the PIs and collaborators of shortlisted projects presented their proposals to the Steering Group, which gave a high priority to likely impact. Ongoing projects are reviewed every six months by an external assessor and the IMCRC Research Manager and/or Director.

Economic Impact Analysis

Funding and Leverage

According to data provided by Loughborough University for this exercise:

- A total of **£34.4 million (cash and in-kind contributions)** has been provided by partners for research at the IMCRC. Thus, for every £1 provided by the IMCRC, £1.08 has been contributed by other partners.

Delivering Human Capital to the Labour Market

Nearly half of former IMCRC staff have been recruited to work in industry which represents a significant transfer of skills from academia to industry.

Approximate proportion[3] of former staff/researchers in:	
Academia	50%
Industry	40%
Government	10%

The case studies illustrate how skills have been transferred into industry through recruitment of research staff and students by partner and related companies. Human capital impacts for each case study are summarised below:

- **Managing value in delivery design case –** The project ultimately helped to support 1 PhD and 1 EngD qualification. The EngD student is currently working in industry for an asset management and construction consultancy, while the PhD student is conducting further research at Loughborough University.
- **Regenerative medicine –** The project has supported 10 PhDs (3 are ongoing) and a number of students have gone on to work in industry. For example, one of the students is currently working for a regenerative medicine company in the United States, one is working for a stem cell company in Manchester and another of the doctoral students is working at the School of Clinical Sciences based at the University of Liverpool.
- **Innovation in Healthcare (E-MEDIC) –** The project supported four graduate research assistant (RA) posts and one post doctoral RA post. In addition, one of the graduate RAs went on to achieve a PhD as a result of working on the project and is now working for TWI, a technology consultancy.
- **Maximising energy expenditure –** 2 of the former researchers on the project are now employed by Reebok Fitness (New Product Development Manager) and Speedo International (Head of Aqualab). The technician for the research group has also been kept on at Loughborough and this helps in terms of helps in terms of providing continuity and expertise on other projects. In addition, a relationship has also been established with the Massachusetts Institute of Technology (MIT) as a result of the research. MIT ranked third among world's top 200 universities according to the Times Higher Education World University Rankings[4]. A PhD student from MIT worked on the project as a placement student and a summer intern programme has subsequently been developed. To date, five summer interns have come to the University and in 2009 one of these interns started a PhD at Loughborough.
- **Design for Rapid Manufacturing** – Two research assistants worked on the project and one now works as a designer at Bentley Motors. On wider scale, the research on rapid/additive manufacturing has supported a number of researchers since the inception of the IMCRC, many of whom have gone on to work in industry for companies such as Dunlop Slazenger and Bombardier.
- **Business Driven Automation** – A number of research assistants and PhD students have worked on the project. By the time the project ends, eight PhD students will have had some of their studies funded by the IMCRC. Up to four of the people who have been involved in the project are now employed by industry. Two have their own software businesses and one of the researchers is working with Rolls-Royce on knowledge transfer activities at the new Manufacturing Technology Centre (MTC) in Coventry. Loughborough is one of the key research partners at the MTC.

[3] These apportionments are approximate and were made following a review of the IMCRC project staff.

[4] Available at: http://web.mit.edu/newsoffice/2010/times-higher-ed-rankings.html

Impact Case Study Selection (detailed case studies below)

Six case studies have been selected by DTZ in conjunction with the IMCRC and EPSRC to illustrate the economic impact of research funded through the Loughborough IMCRC as shown in the table overleaf. These case studies have been selected on the basis of the agreed shortlisting criteria, as follows:

- Demonstrates a range of types of economic impact as defined by BIS
- Offers convincing evidence of significant tangible impact
- Demonstrates the added value of the IMCRC model
- Provides good coverage of the different research themes within the IMCRC
- Provides good coverage of relevant sectors.

The key points relating to case study selection are as follows:

- The Next Generation Technologies theme accounts for around £22 million of the research undertaken and 156 of the 214 projects incorporate all or part of this theme. Three case studies have been produced, one highlighting actual impacts on the sports equipment market, while another looks at the potential opportunities for additive manufacturing. The Regenerative Medicine Grand Challenge also falls within Next Generation Technologies and this is included as a case study.
- Given the significance of Loughborough's role in the construction sector, a construction case study has been produced identifying value in the design process of buildings. Retrospectively, this research falls within the Transforming Organisations theme. The Health and Secure Future theme is covered by the Regenerative Medicine Grand Challenge and sports technologies research, while the Business Driven Automation project falls within the High Value Assets theme (as well as including aspects of Next Generation Technologies).

Case study	BIS Impact Headings[1]	Added Value Aspects	IMCRC Research Theme	Sector
Managing Value Delivery in Design	Public Policy & Services New business creation	Industry collaboration Critical mass of knowledge	Transforming organisations	Construction
Regenerative Medicine	Improving existing businesses (competitiveness)	Inter-disciplinarity Critical mass of knowledge Industry collaboration	Healthy & Secure Futures Next Generation Technologies Customised Products	Healthcare
Innovation in Healthcare by Combining Electronics, Drug Formulation and Delivery and IT	Improving existing businesses (competitiveness)	Critical mass of knowledge Inter-disciplinarity Industry collaboration	Healthy & Secure Future	Healthcare
Maximising energy expenditure whilst minimising perceived exertion: development of a new exercise platform	New business creation Improving existing businesses (competitiveness)	Industry collaboration Critical mass of knowledge	Next Generation Technologies	Healthcare

Case study	BIS Impact Headings[1]	Added Value Aspects	IMCRC Research Theme	Sector
Design for Rapid Manufacturing	Public policy and public services	Industry collaboration Critical mass of knowledge	Next Generation Technologies	Other (Manufacturing)
Business Driven Automation	Improving existing businesses (competitiveness)	Industry collaboration Critical mass of knowledge	High Value Assets Next Generation Technologies	Automotive

[1] Most projects have attracted R&D investment through industry contributions and developed human capital so these are not listed as a type of impact as they would apply to all the projects

Added Value of the IMCRC Model

In total, 26 stakeholders from industry and academia were consulted in order to information the IMCRC case study. A key area of discussion was the extent to which the IMCRC funding model has created added value. A summary of the main points raised by stakeholders in relation to this is provided below:

- **Greater continuity for both industry and academia**. Under responsive mode funding, there may be the risk that a research area with significant potential cannot be continued before further funding is secured. This could lead to key staff leaving and relationships with industry not being exploited fully. The IMCRC structure has meant that promising areas of research can be developed over time. Projects have clearly built on antecedent projects and/or been built upon by later pieces of research. In many cases, several successive links in these chains of research have been funded by the IMCRC. Of the six case studies discussed in the next sections, examples of this include the Design for Rapid Manufacturing project, Managing Value Delivery in Design and the Regenerative Medicine Grand Challenge. Across the whole IMCRC the research leaders report that they now address industrial research problems with much greater ambition than previously and therefore have been willing to tackle more innovative steps.
- It **has encouraged multidisciplinary working across the University and externally**, drawing on the expertise of a number of departments at Loughborough. The IMCRC has also encouraged working with other institutions. For example, the E-Medic project drew in support from Bath and Southampton, while the Regenerative Medicine Grand Challenge included Birmingham, Cambridge, Liverpool, Nottingham and Ulster. Continuity of IMCRC funding has also given confidence to build an extensive network of overseas collaborators.
- Significantly, **the IMCRC has allowed Loughborough to develop new links with industry and develop links already in existence**. This has enabled the research to become more responsive to the needs of industry, with the IMCRC able to provide the resources if a particular research opportunity emerges. Good examples of responding to industry needs include the Business Driven Automation project which involves Ford and the sports technology research which collaborated closely with Reebok Fitness.
- Furthermore, **the stable long term partnerships with industry have given confidence to other funding bodies to support major new initiatives such as**: the Sports Science Institute in a new dedicated building (supported by East Midlands Development Agency); Loughborough's part in the new Manufacturing Technology Centre being constructed in Coventry (emda and Advantage West Midlands); and the IMCRC seeded the Regenerative Medicine programme through a Grand Challenge award (now an EPSRC Centre for

Innovative Manufacturing in its own right). These are examples of significant capacity building which will outlast the pump-priming impact of the IMCRC itself.

- A **more strategic approach towards the management and development of research has evolved over time**. Responsive mode funding makes it difficult to develop a strategic research programme, given that the people involved will have no control over what is funded. Project proposals are overseen by the IMCRC Director and/or Research Manager, while the use of an International Review Panel ensures that the research is not only strategic but internationally competitive. For example, the Design for Rapid Manufacturing project has enabled the IMCRC to structure a research programme around this issue. Large proposals have been refereed and then judged by the Industrial Steering Group. This happened notably with the "Integration Projects" intended to encourage multidisciplinary research within the IMCRC, Thus the continuity of the IMCRC has allowed an internal peer review and full research selection process to be implemented for the first time.

Consultees

The following people at Loughborough University were consulted and reviewed a draft of the report:

- Professor Andrew Baldwin
- Dr James Bishop
- Professor Phill Dickens
- Professor Andrew Dainty
- Dr Chris Stokes
- Professor Peter Davies.

Case Study 1: Managing Value Delivery in Design

Key Facts	
Time Period	2002-2005
IMCRC Funding	£154,000
Other Funding	£300,000 (Industrial contribution) & £154,000 (DTI)
Collaborator(s)	Adept Management, AMEC, Arup, BAA Plc, Broadgate Estates Limited, CABE, CIBSE, Collaborative Working Centre – Constructing Excellence in the Built Environment, Davis Langdon LLP, RIBA, RICS, Sheppard Robson.
IMCRC Research Theme	Transforming Organisations
Research Output	The project created Value in Design (VALiD), a set of theoretical and practical methods to help stakeholders state what they each considered value to be and whether or not they were judging a project solution to be fulfilling their expectations.
Pathway to Economic Impact	**Spin Out Company -** Research findings were taken forward by ADEPT Management Limited, a Loughborough University spin out company. Manchester City Council has subsequently taken on board some of the findings in relation to its new build schools programme.
Actual Economic Impact	**Informing new build construction projects** - used by Manchester City Council as part of an integrated approach to informing the design process for 6 new primary schools costing around £36 million.
Potential Economic Impacts	The impacts discussed in this case study (both economic and qualitative) are actual. However, given the ongoing research being undertaken further impacts are likely to arise in the future.
Sector Focus	Construction

Context

Published in 2002 by the Strategic Forum for Construction, Accelerating Change[5] outlined a vision to realise maximum value for all clients, end users and stakeholders and exceed their expectations through the consistent delivery of world class products and services. The report went on to highlight that the UK construction industry must *"exploit the economic and social value of good design to improve both the functionality and enjoyment for its end users of the environments it creates."*[6]

Despite the importance of 'value' being raised by Accelerating Change, there was no clear indication at the time as to how to create or measure it. A key consideration is that stakeholders involved in a construction project must be enabled to understand and express value in their own terms, then share and align these expectations for value delivery by making assessments during design, construction and use – i.e. being involved right throughout the process.

Historically, the construction industry has focused more on managing the technical and process complexity of design and construction, rather than addressing the human side of its activities. Construction projects are socially complex because they involve and affect many different people, leading to varying opinions as to what a particular project should be doing. For example, when constructing a building stakeholders include:

[5] Accelerating Change: A Report by the Strategic Forum for Construction, Chaired by Sir John Egan. September 2002

[6] *Ibid,* page 10

- The owner/landlord
- Tenants who occupy the building in the course of their business
- Other people using the building.
- People who will walk past the building but might never go inside it

Each stakeholder will have a different understanding of value and a different expectation for the building's realisation. As an example[7]:

> The value of a building or project can be expressed on a scale of 1 to 10. The architect thinks that the building offers a value of 8, while the facilities manager and client think the building's value is 5 and 6, respectively. A person walking by on the street, thinks that the same building has 4 units of value, yet his friend alongside him considers the building's value to be 5.

Taking into account these different opinions, the quality of a building should be measured by how closely it meets the values of the people for whom it was designed and constructed. Such a change would acknowledge that in whole-life terms the construction cost is a fraction of the running costs and an even smaller percentage of staff employment costs. However, a number of barriers need to be addressed in order to achieve this change:

- A poor understanding of value and values
- A lack of focus on customer satisfaction
- Understanding where value resides in the emerging design solution
- The assumption that briefing is complete after concept design.

The IMCRC Project

Based on the context outlined above, the IMCRC project was developed with the aim of increasing customer satisfaction through a better shared understanding of stakeholder value, through the development of standard methods for structuring value delivery. The research built on previous work undertaken at Loughborough, including a project funded by the EPSRC Innovative Manufacturing Initiative looking at integrated collaborative design in process, supply chain and value management.

The main objectives of the study were to:

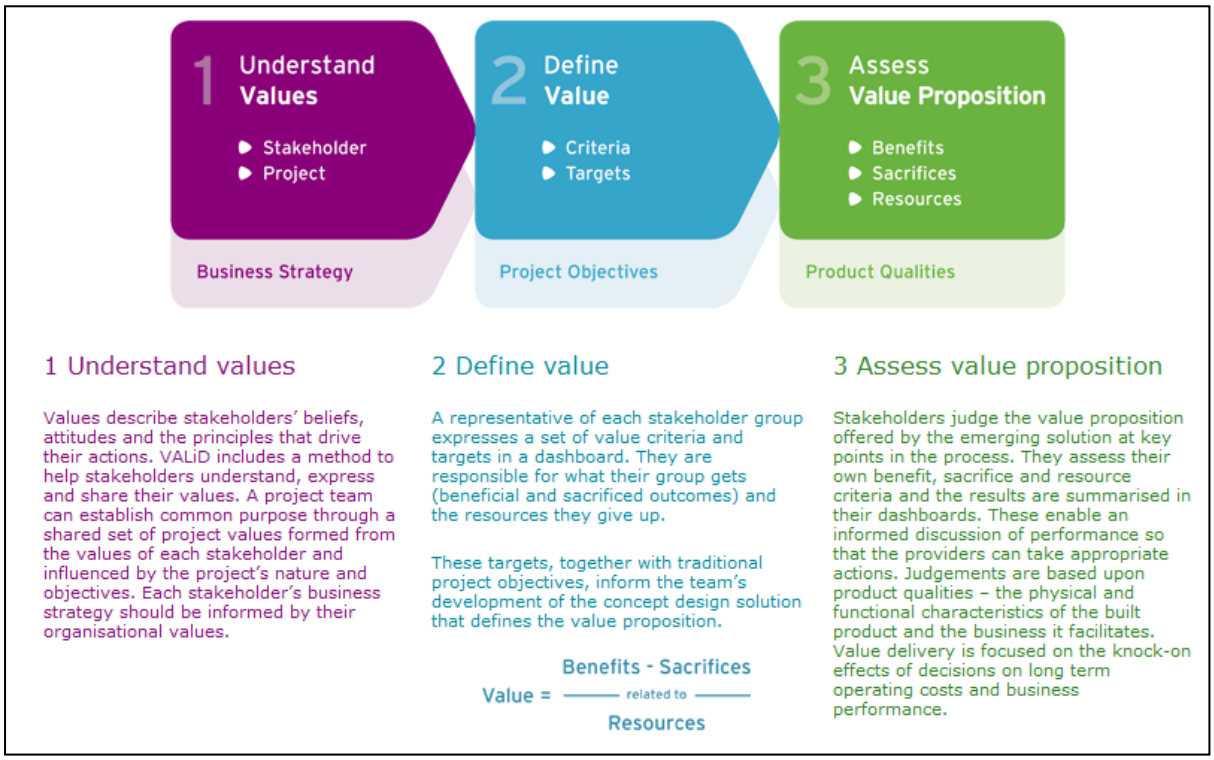
- Develop a common value culture and language for clients, users and designers
- Provide standard mechanisms that capture and communicate an evolving set of project values
- Relate design tasks to project values, justifying their outcomes and monitoring overall project effectiveness regarding value delivery and hence user satisfaction upon occupation
- Recommend implementation strategies to encourage uptake and provide appropriate training.

[7] Based on information available at: http://www.valueindesign.com/principles/principles.htm

Working in collaboration with industry, a new approach to value delivery was created. Called VALiD (Value in Design), it comprises a suite of methods that take people's judgements and use them to understand stakeholder value and to demonstrate project performance.

A key output from the research was the VALiD framework and supporting dashboard, measurement techniques and user documentation, which provides a logical structure to help project teams understand the issues that must be discussed among stakeholders if value, and the drivers for its delivery, are to be fully understood. The framework comprises three elements to guide stakeholders through the discussion of their values when assessing project performance in delivering value and these are summarised in Figure 3.

Figure 3: The VALiD Framework



Source: Valueindesign.com

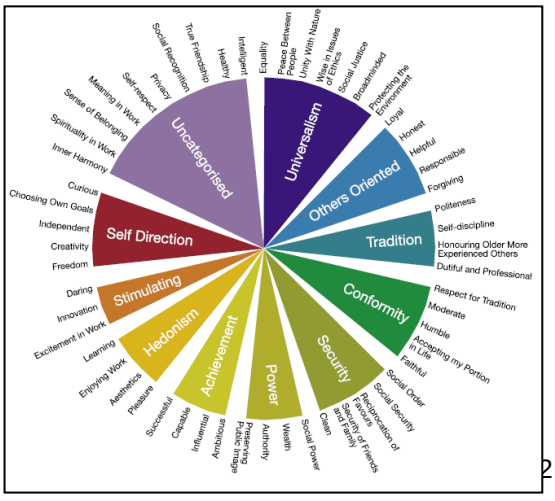
VALiD offers a series of activities that align with relevant stages of a project. An appropriate set of activities is selected for a particular project and linked to its delivery process. These will change as the project progresses to reflect its shifting focus but can include:

A Value Survey

A structured method (Figure 4) of revealing values can help an organisation understand itself and drive its business strategy. It also helps individuals understand how their values frame their judgements of value.

A universal values model can assist organisations in understanding each other and finding common project values. When stakeholders recognise project values consistent with their own they are more likely

Figure 4: Value Survey



to identify with the project, feel a sense of belonging to it, and acquire a stake in achieving its objectives.

The Dashboard

Dashboards provide quick and simple "at-a-glance" summaries of value delivery for the team. They present information that steers the project to a successful conclusion and, in particular, give designers insight into what stakeholders seek and how well they are fulfilling those expectations.

The size of a dashboard is controlled to balance the additional insight offered by a greater number of benefits, sacrifices and resources with the increase in time and effort required to judge their delivery during the project.

Approaches such as the value survey and dashboard help stakeholders to set targets for value delivery and judge project performance in fulfilling them by structuring metrics for each stakeholder's benefits, sacrifices and resources in stakeholder and project dashboards. The findings from these approaches can then be fed back to a project design team to ensure effective project value delivery.

The findings from this research project have been taken forward by Loughborough University spin out company ADEPT Management Limited, which is exploiting the research outcomes and helping industrial take up.

Assessment of Economic Impact

The economic impact of the project can be assessed with a case study example of how some of the principles and processes behind VALiD were used to inform the build design process at Manchester City Council for a new primary school.

In a follow-on project (Applying VALiD to Construction Investment Decisions and Project Management), part funded by the IMCRC[8], a Research Associate at Loughborough University applied the VALiD approach to one of the projects in the Educational Capital Programme at Manchester City Council. The project related to the design of the new Medlock Primary School and Children's Centre.

Manchester City Council was already utilising a number of project management practices, in addition to the Design Quality Indicator[9] and DfES recommended stakeholder consultation processes in relation to school buildings. However, it was recognised that construction projects must deliver greater value in order to build cohesive communities and demonstrate corporate social responsibility. In response to this, the City Council collaborated with Loughborough to develop a new approach to stakeholder delivery and demonstration, putting stakeholder expectations at the heart of the project management process.

Significantly, a number of the VALiD principles were integrated with existing City Council project processes and applied to the design process for the new school in Medlock. In particular, VALiD was simplified to assess four key project interventions:

- **Value 0:** Defining value
- **Value 1:** Assessing the value of space
- **Value 2:** Assessing the value of building elements

[8] IMCRC grant - £83,000. Industry contributions (in kind) - £92,500.

[9] The Design Quality Indicator for schools provides a method of evaluating the design and construction of new school buildings and the refurbishment of existing buildings.

- **Value 3:** Assessing quality in construction and occupation.

In line with the main VALiD principles, a range of stakeholders were engaged and this included the Local Education Authority, teachers, the general public and the construction partners. The findings from the assessment of Values 0-2 were fed into the initial design review and outline planning submission for the school, while Value 3 was used to provide final validation for the design.

In a report the impact of the new approach (October 2007) the Council identified a number of benefits of VALiD including:

- Providing a better understanding of stakeholder needs, expectations and perceptions of value delivery
- Improved communication, information flow, confidence and feedback between stakeholders
- The stimulation of stakeholder ideas on school specific built spaces and teaching apparatus

The new school in Medlock opened in 2006, at a cost of approximately £6 million. Furthermore, since the original project Manchester City Council has used the new integrated approach for assessing value at five more primary schools, each costing around £6 million. **In total, this means that the VALiD approach has been used to help inform the design process for new primary schools in Manchester worth around £36 million since 2005/2006.**

The success of the integrated approach has led to the City Council applying the most relevant parts of VALiD to the D.Q.I. process on its Building Schools for the Future Programme for secondary schools, which represents a total investment of £500 million.

Wider Impacts

The research has also had a significant impact at a qualitative level and this can be assessed as follows:

- Assessing value at an organisational level
- Informing policy
- Industry training and education
- Informing whole life value
- Ongoing research

Assessing Value at an Organisational Level

Currie & Brown is an asset management and construction consultancy. As part of an EngD project, the company sponsored one of its employees to undertake research aimed at developing organisational values and behaviours for the business – using the VALiD approach. A values task group was established with 30 employees that over a 2 year period negotiated a set of company values and behaviours with the CEO Euan McEwan. The company's website notes that *"Our values were established through an organisation-wide staff consultation and a series of values workshops, which involved members of staff at all levels. Currie & Brown is justifiably proud of this unique bottom up approach, an approach that has ensured our values reflect both our business and staff."*[10]

[10] Available at: http://www.curriebrown.com/standard.php?page=vision

Informing Policy

A key policy document of Constructing Excellence, the pan-industry body established through a combination of government and industry initiatives, is Be Valuable[11]. Published in 2005, it aims to provide a better understanding on the subject of value in the built environment and to make it useful for customers/suppliers. The thinking and tools within the VALiD approach were highly influential in shaping the Be Valuable document. In particular, Constructing Excellence adopted the VALiD definition of value (Value = what you get divided by what you give).

Simon Austin, who led the VALiD project at Loughborough, was subsequently invited to become a member of the task group that authored Constructing Excellence's 2009 report Never Waste a Good Crisis[12]. This has received much publicity from its 10-year review of Egan and recommendations for action and has had a significant influence on the Chief Construction advisor Paul Morrell and the Innovation and Growth Team's Low Carbon Construction final report[13], which was published in 2010. VALiD has also been integrated with the Design Quality Indicator (DQI) developed by the Construction Industry Council, as part of a whole life value approach. The DQI identifies the attributes of buildings that constitute high design qualities under three main headings: functionality; build quality; and impact.

Outside the UK, VALiD was selected by the Dutch Government Building Agency (VROM) as a way to improve value in public projects. They purchased a 2-day training programme and software license in 2008 with early applications on police stations.

Industry Training and Education

From an industry perspective, many professionals have been trained in the VALiD approach since 2004 as part of the Institution of Civil Engineers' Thomas Telford[14] ongoing training course in Managing the Design Process. To date, approximately 360 delegates have attended 26 three-day courses, representing over 200 companies from the UK and abroad. Three UK organisations have also had company-specific training programmes, together with one in the US.

The VALiD is also having an impact in Higher Education. In particular:

- At the School of the Built Environment, Heriot-Watt University the processes and approaches are taught to undergraduate (D30VM: Value Management and Measurement) and postgraduate (D31VR: Value and Risk Management) construction management students
- They are also delivered to undergraduate and postgraduate graduate (CVD004 and CVP010: Management of the Design Process) students in the Department of Civil and Building Engineering at Loughborough University

The courses outlined above assist Loughborough and Heriot-Watt in differentiating their education programmes, however the primary impact from such diffusion via education will accrue in the longer term because a new generation of construction managers are being educated in the use of VALiD.

---

[11] Constructing Excellence in the built environment (2005). "Be Valuable: A guide to creating value in the built environment"

[12] Constructing Excellence in the built environment (2008). "Never Waste a Good Crisis: A Review of Progress since Rethinking Construction and Thoughts for Our Future"

[13] HM Government, Innovation and Growth Team (2010). "Low Carbon Construction: Final Report"

[14] Thomas Telford is the knowledge business of the Institution of Civil Engineers, creating specialist products and services for the civil engineering and construction markets

Their ability to deliver value for clients will be markedly improved with the insights into the nature of value and the operationalised forms of stakeholder engagement offered by VALiD.

Informing Whole Life Value

Axoss Ltd, the value management consultancy of Professor John Kelly, an internationally-renowned value management academic and practitioner, has developed an approach to modelling the whole life value of building investments for the South West Regional Improvement and Efficiency Partnership (SWIEP).

The approach marries established construction value management techniques, whole life cost modelling, and the core VALiD operationalisation of "value" as the relationship of benefit with sacrifices and resources. In this case, benefits are represented as the functionalities required from a building and sacrifices are merged with the VALiD concept of resources to represent its whole life costs.

The whole life value modelling method was tested and validated during summer 2010 by a member of the Managing Value Delivery in Design project team. It is now part of the procurement processes of SWIEP member Local Authorities. SWIEP members are compiling a database of value outcomes from its applications to provide benchmarks for future building investments. This will generate considerable impact throughout the South West as effective investment will be assured through the appropriate balancing of capital with operating expenditure.

Ongoing Research

Recent and current research has built on VALiD at Loughborough and internationally in construction and other sectors. For example, it is assisting stakeholder engagement in healthcare and urban environments within the Health and Care Infrastructure Research and Innovation Centre (HaCIRIC) and EPSRC/ESRC Sustainable Urban Environments programme[15]. Both of these are major multi-university programmes funded by EPSRC and ESRC outside the IMCRC. Another IMCRC-funded project, Adaptable Futures, has also created multi-party benefit maps to assist in whole-life assessments of the value of more adaptable buildings.

Position without IMCRC Funding

When assessing the economic impact of research it is important to consider the rationale for IMCRC investment in the research. The only rationale for IMCRC investment in research should be to address a market failure of some kind. In other words, there should be a reason why industry itself would not fund the research and why public intervention through the IMCRC is justified[16].

The rationale for EPSRC funding for this project was to develop a new approach to value delivery in order to ensure the quality of a building meets the values of the people for whom it was designed and constructed. Industry would not have been prepared to pay the full cost of this research because there was no guarantee that the research would ever be commercialised.

The research undertaken involved significant levels of collaboration with industry and also built on work undertaken prior to the establishment of the IMCRC.

[15] www.sue-mot.org.uk

[16] This definition remains the same for each IMCRC project, therefore it is not repeated in the other case study write ups.

Consultees

The following people were consulted and reviewed a draft of the case study:

- Professor Simon Austin, Loughborough University
- Dr Grant Mills, Loughborough University
- Dr Derek Thompson, Heriot-Watt University
- Simon Robinson, Currie & Brown
- Ged Mitchell, Manchester City Council
- Bernard Core, Manchester City Council.

Case Study 2: Regenerative Medicine Grand Challenge

Key Facts	
Time Period	2005-2010
IMCRC Funding	£1.6 million
Other Funding	£6.5 million (Industry cash, other EPSRC funding and in-kind contributions)
Collaborator(s)	University of Birmingham, University of Cambridge, University of Liverpool, University of Nottingham, University of Ulster, The Automation Partnership, Regentec Limited, Critical Pharmaceuticals, Association of British Healthcare Industries, Medilink East Midlands, NHS Innovation East Midlands, NHS Confederation, *edma,* Intercytex, National Physical Laboratory, National Institute for Biological Standards Board.
IMCRC Research Theme	Heath & Secure Future (70%), Next Generation Technologies (20%), Customised Products (10%)
Research Output	Delivery of a new multi-perspective understanding of the trajectory of the regenerative medicine industry and its stakeholders. The research has also driven the development of new industry standards and supported the creation of a trade association. New techniques to characterise, monitor and control regenerative medicine products and their production have also been developed.
Pathway to Economic Impact	**Via collaborator(s) –** The Automation Partnership has developed a new automated cell culture system which has generated significant revenues. The timescales for many of the outputs from the research are long so it will take time for actual economic impact to be realised.
Actual Economic Impact	**Development of a new automated cell culture system** - £21.5 million of sales achieved to date by The Automation Partnership, one of the project partners **Follow-on funding** - £28 million in additional funding to undertake further research into regenerative medicine.
Potential Economic Impacts	**Helping the UK capture a share of the future regenerative medicine market** - DTZ estimates a 0.5% share of this market would represent about £650 million per year (based on the projected size of the market in 2025).
Sector Focus	Healthcare

Context

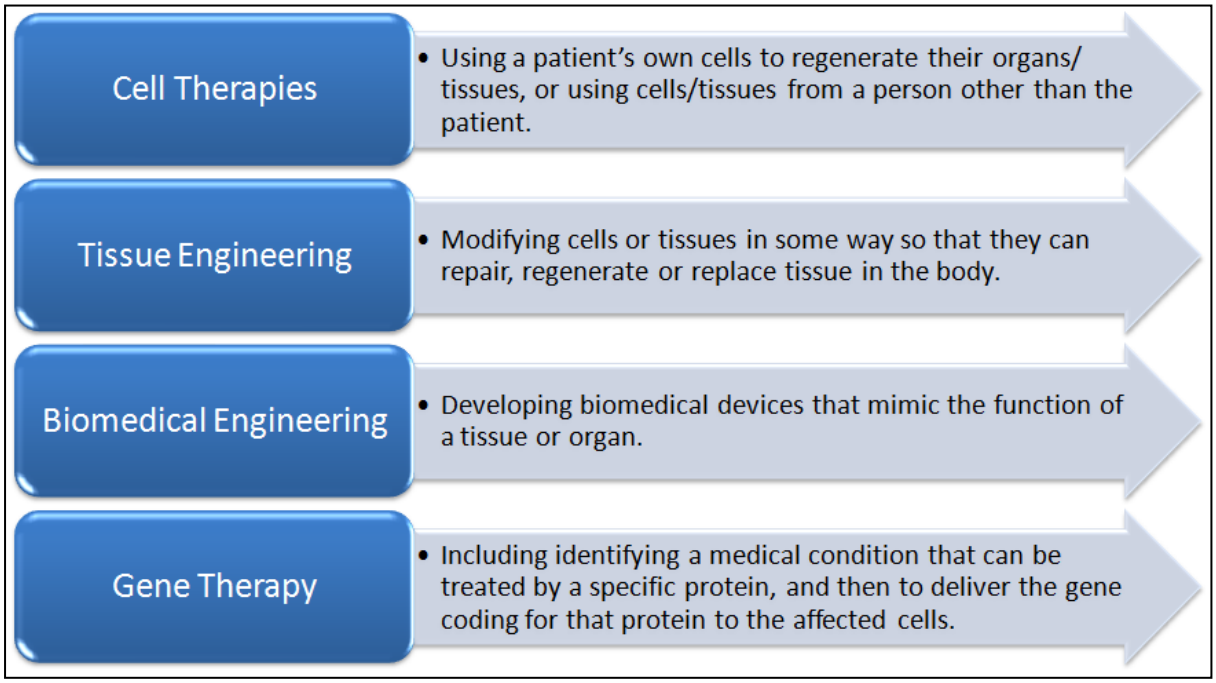
Regenerative medicine aims to restore the function of diseased or damaged tissues or organs by a variety of approaches, from cell-based therapies through tissue engineering to developing new medical devices.

Diseased, degenerating or damaged organs and tissues give rise to a wide range of chronic illnesses. Patients suffering from such illnesses are currently faced with a relatively short list of options. These include:

- Long-term drug therapy, which may allow a disease to be managed but rarely cures it
- Organ transplant (there is a shortage of donor organs)
- Medical devices such as pacemakers.

Regenerative medicine therefore represents a major innovation in healthcare. In the long term, it could provide the ability to repair and replace damaged cells and tissue. The industry aims to restore the function of tissues and organs by a variety of approaches, which are illustrated in Figure 5.

Figure 5: Types of Regenerative Medicine[17]



Source: Parliamentary Office of Science and Technology[18]

The science behind regenerative medicine is rapidly becoming established, however the industry required to underpin the clinical realisation of regenerative medicine is lagging behind. While there has been a realisation of the potential for regenerative medicine products, in terms of their efficacy, there is a need for the development of consistent manufacturing and appropriate business models. Research undertaken at the IMCRC seeks to address this trend.

The IMCRC Project

Remedi was one of the four Grand Challenge projects awarded by EPSRC in 2003 from their Innovative Manufacturing and Life Sciences Interface Programmes. The overall aim of the Grand Challenges was to address major research challenges with the potential for significant impact on national manufacturing priorities, and ambitions far greater than might be achieved by a single research team or in the span of a traditional research grant. The Remedi Grand Challenge portfolio sought to demonstrate how established bioscience could be transformed into profitable commercial practice and generate affordable therapies, while developing the science of manufacturing.

The original vision of Remedi was captured by four high level objectives:

- Demonstrate how established bioscience can be transformed into profitable commercial practice and generate affordable therapies, while developing the science of manufacture

[17] The Remedi project focused on cell therapies and tissue engineering.

[18] Sourced from: Postnote, number 333. Regenerative Medicine. Published by the Parliamentary Office of Science and Technology, May 2009.

- Determine the value of tissue engineered products to users in healthcare, define the market place and show how the development of regulation and industrial policy can maximise the benefit to the UK and patients

- Create and demonstrate reproducible and cost-effective processes for the production of cells, scaffolds and tissue products that satisfy the regulator and take advantage of emerging process, sensing and control techniques

- Construct a community that holds a shared vision for the industry and its products, and explores those visions practically

The research was organised as five work packages, which are summarised below:

- **Work package 1:** Comprising two components, the first of which addressed market structure and barriers within the market. The second assessed health economic issues, in particular pricing

- **Work package 2:** Focussing on the policy environment, particularly from a European regulatory perspective and from a UK level industry growth perspective

- **Work package 3:** Focussing on product processing with demonstrators/sub work packages in scaffold, cell and tissue processing

- **Work package 4:** Addressing characterisation and control, especially from a process perspective both acting as a "service" work package to work package 3 and addressing more novel work

- **Work package 5:** Including project management and subsequent work triggered by the mid-term review focussing on the growth of individual SME's and Good Manufacturing Practice. It also included more speculative content in injectable scaffolds and in electrophysiology tools.

The timescales for many of the outputs from the research are long so it will take time for them to be translated into outputs which create economic impact. However, the research undertaken as part of work package 3 has been applied by The Automation Partnership in the development of a new automated cell culture system.

Assessment of Economic Impact

The economic impact of the project can be quantified as follows:

- Development of a new automated cell culture system

- Follow-on investment

- Helping the UK capture a share of the future regenerative medicine market.

Development of a new automated cell culture system

Working closely with The Automation Partnership (TAP), one of the first deliverables from Remedi was the development of a new automated cell culture system for smaller biotechnology companies. To date, TAP has generated £20 million in revenues from the sale of these systems since 2008. In addition, a more recent version of the system which conforms to Good Manufacturing Practice was released. This can be used in hospitals and has generated revenues of £1.5 million, a figure which is expected to increase in the future. **In total therefore, Remedi has helped to deliver new cell culture systems which have generated total revenues of £21.5 million up to January 2011.**

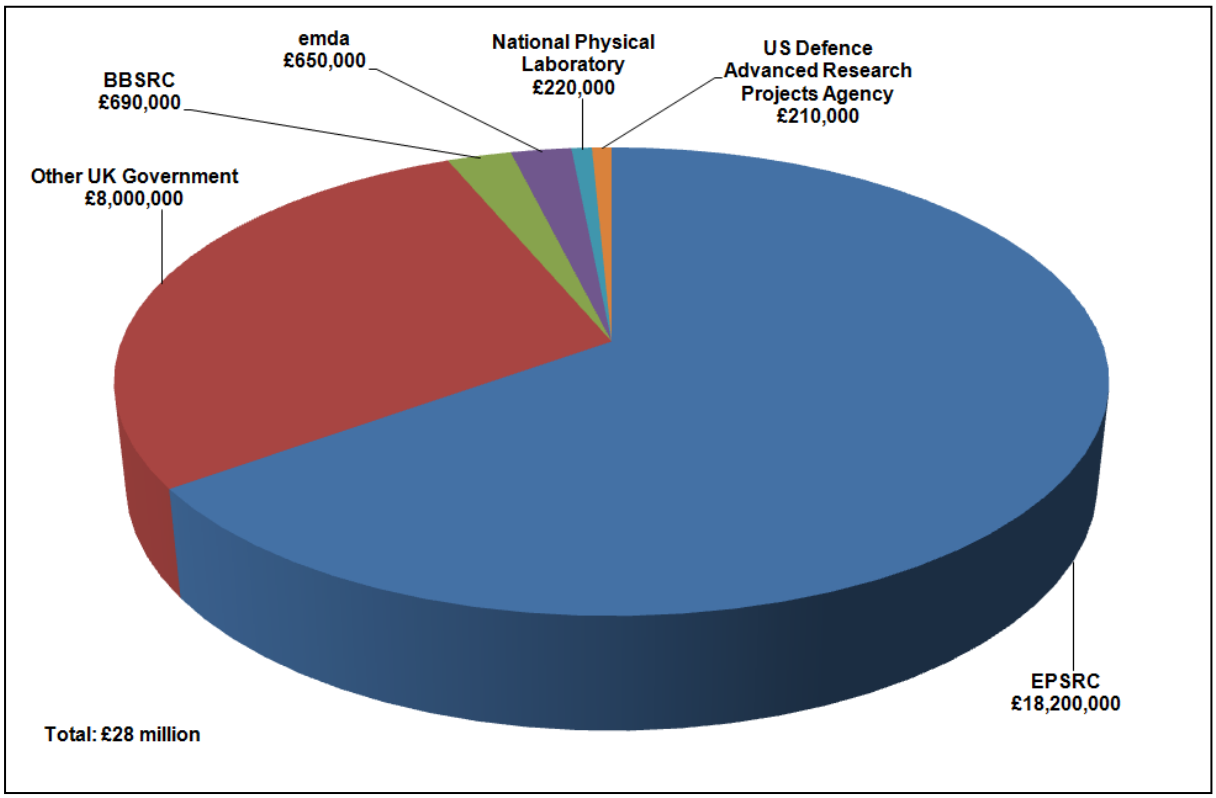
It was noted in the final report for Remedi in May 2010 that the manufacture of the cell culture machines takes place in the UK. Annual Business Survey data shows that the average turnover per employee in the manufacture of medical equipment stood at approximately £130,000 in 2008. Dividing this into the £21.5 million of revenues suggests that **the manufacturing process is helping to support more than 160 jobs in the UK.** These are direct jobs and there will be other significant wider economic benefits from spending associated with these jobs – for example, expenditure in the wider supply chain.

Follow-on Investment

The Remedi Grand Challenge ended in 2010, however one of the most important impacts has been the follow-on funding it has helped to bring. The final report for Remedi gave a detailed description of the amount and source of follow-on funding, which totals approximately £28 million. This includes £18 million from EPSRC and £8 million from other UK government sources such as the Technology Strategy Board (see Figure 6). A key strand of the additional EPSRC money relates to £5.3 million for the creation of the new Centre for Innovative Manufacturing in Regeneration and the aim is to build on many of the findings from Remedi.

Work is also being undertaken for the US Defence Advanced Research Projects Agency (DARPA) researching red blood cell production, which could have applications for the military while out in the field, for example.

Figure 6: Follow-on Funding for Remedi



Source: Remedi Final Report, 2010

Helping the UK capture a share of the future regenerative medicine market

According to a report published by Life Science Intelligence in 2009[19], the actual market for regenerative medicine was estimated at $1.5 billion in 2008. More significantly, in the longer term the potential market for tissue engineering and regenerative medicine products is forecast to grow significantly.

The United States, which accounted for 90% of the global market in 2008, is expected to remain the largest and market and witness rapid growth. However, over the forecast period, the markets in Europe, Japan, and Rest of World are forecast to grow at significantly higher rates compared to the U.S.

Substantial growth is expected in multiple product segments. Target procedure areas with high volume and/or high growth potential include neurologic, orthopaedic, organ regeneration, cardiovascular, urologic, and wound care. In addition to high potential in various clinical procedure areas, major opportunities exist in international markets as a whole.

The research undertaken as part of Remedi will help to capture some of the opportunities created as the industry develops. For example, the automated cell culture system discussed above is already generating significant revenue streams. In addition, the project has supported the creation of the Regenerative Medicine Industry Group within the Bio Industry Association. It has also informed the development of new standards for the industry in conjunction with BSI British Standards. This is particularly important for regenerative medicine and the standards will help to shape the industry by providing the ability to demonstrate compliance with widely recognised and respected standards in a competitive marketplace. Working closely with the Remedi team, three standards have been created:

- Publicly Available Specification (PAS) 83 (2006) – Providing guidance on codes of practice, standardised methods and regulations for cell-based therapeutics. A revision is currently being produced and this will be released by Easter 2011.

- PAS84 (2008) – Defining the terms commonly used in the field of regenerative medicine and providing clear guidance on the meaning of terminology currently used in the UK by industry, regulators, government and academia. The aim is to help key stakeholders to communicate more effectively and allow the commercialization of the new technology to take place more efficiently and safely. A revised version will be released in summer 2011.

- PAS93 (by Easter 2011) – This will be a guide to the characterisation of cell-based products. It is being produced to help people establish what they need to demonstrate to regulators when they are developing products.

In terms of specific information on the economic value of regenerative medicine, the 2010 Translational Regenerative Medicine conference estimated the market could be worth up to around £130 billion annually by 2025[20].

DTZ has estimated that if the research undertaken as part of Remedi enabled the UK to gain a 0.5% share of this market[21], it would still represent approximately £650 million per year (based on the size of the market in 2025). Annual Business Survey data shows that the average turnover per employee in the life sciences sector stood at approximately £160,000 in 2008, suggesting that an additional

[19] Worldwide Markets and Emerging Technologies for Tissue Engineering and Regenerative Medicine.

[20] Figure converted into £ from $208 billion (using conversion rate of $1=£0.63). Estimate available at: http://www.visiongain.com/Conference/236/Translational-Regenerative-Medicine

[21] The use of market shares is intended to provide an indicative view as to what the impact of the research could be. Where possible, the estimates have been verified with stakeholders.

£650 million could support around 4,000 jobs in the UK. If multiplier effects are taken into account, there would be significant wider economic benefits from spending associated with the wider supply chain, for example.

Of course, these are only indicative DTZ estimates since it is too early to assess the level and type of market share the UK could capture in the future.

Position without IMCRC Funding

Public sector intervention in the Regenerative Medicine Grand Challenge was necessary to provide social benefits that are large in comparison to their private benefits. Such investment is known as a "public good". Investment in the Grand Challenge research may ultimately benefit all of society through reduced disease, for example.

There is little incentive for any individual company in the industry to bear the full investment, particularly when success is not guaranteed, unless they can secure exclusive use of any new products/innovations. The IMCRC funding also supported the creation of a multi-disciplinary project team that would not otherwise have existed.

Consultees

The following people were consulted and reviewed a draft of the case study:

- Professor David Williams, Loughborough University
- David Newble, Chief Executive – The Automation Partnership
- Ben Sheridan, BSI Group.

Case Study 3: E-MEDIC

Key Facts	
Time Period	2001-2004
IMCRC Funding	£82,000, in addition to a further £289,000 from EPSRC
Other Funding	£783,000 (Industrial contribution)
Collaborator(s)	University Bath, University of Southampton, Bespak[22], CSW Health Limited, Vectura
IMCRC Research Theme	Healthy & Secure Future
Research Output	Development of platform technologies to support improved delivery of drugs to the lung.
Pathway to Economic Impact	**Via collaborator –** Vectura, one of the project partners, has developed a new powder-based inhaler using some of the research outputs.
Actual Economic Impact	Due to commercial sensitivity, details on the inhaler developed using some of the research outputs cannot be disclosed. The economic impacts are therefore potential rather than actual.
Potential Economic Impacts	**Development of a new power based inhaler –** DTZ estimates that achieving a market penetration of 1-2% would equate to annual revenues of between $52 million and $104 million.
Sector Focus	Healthcare

Context

Pulmonary drug delivery devices provide a unique mechanism for non-invasive delivery of local and systemic therapies through inhalation and subsequent absorption (where required) via the airways. This includes treatments for asthma, which affects more than 5.4 million people in the UK alone[23]. Existing devices are primarily mechanical. Newer breath actuated inhalation devices can be difficult to use for a number of patient groups, including those who would benefit most from their use such as the geriatric and paediatric. In addition, the failure to take medication or the inability to take it as designed, is both wasteful in terms of product and potentially fatal for the patient.

The efficiency of delivery of drugs to the lung is critical to the clinical effectiveness of therapies delivered by the pulmonary route, including asthma, chronic pulmonary obstructive disease (COPD) and cystic fibrosis. One way in which delivery could be made more efficient would be to add a monitoring capability to inhalers to ensure patients are taking the correct dosage of a particular drug. However, prior to the E-Medic research a number of questions remained unanswered in relation to linking existing mechanical devices to information and flow monitoring systems in order to develop the ideal pulmonary delivery device. A number of elements needed to be integrated into a single device for dry powder therapies and the research undertaken at Loughborough was developed against this background.

The IMCRC Project

E-Medic was a collaborative project between the universities of Loughborough, Bath and Southampton. It explored the business and technological potential of integrating advanced electronics

[22] Bespak formally withdrew from the project in 2002.

[23] http://www.asthma.org.uk/news_media/media_resources/for_journalists_key.html

and information technologies with improved drug formulations into non-invasive drug delivery devices. The research aimed to answer the following questions:

- What were the precise needs of the healthcare system for future pulmonary drug delivery devices, and could they be translated into an achievable technology specification?
- What were the clinical and potential regulatory constraints and issues and how could these be minimised through testing, design and construction?
- What were the barriers to embedding and integrating of these products into a modern healthcare system?
- Could the drugs be optimally formulated for delivery through such a product configuration?
- Could a technology strategy be defined and demonstrated that integrated the electronic, sensor, control, actuation, materials and manufacturability of the product within the identified business constraints?

In summary, the project was focused on the development of technology to deliver dry powder drugs to patients in a fully controlled manner, such as for treatment of asthma and diabetes. Loughborough University concentrated on analysis of flow in devices and investigated the potential of recording when a device is used and the dosage taken – creating a patient diary.

Bath University was engaged in the reformulation of dry powder drugs and Southampton University was engaged in the 3D video measuring. The project developed 'informatics' to take information from the delivery device, such as how deep into the lung the drug has penetrated. This was achieved using Southampton's sensing technology to measure the cloud of powder in the throat. Bespak, the prime contractor on the project, withdrew after 18 months and a spin-out company (SPInformatics) was therefore developed to take on the management role of E-Medic.

Significantly, platforms developed by the research were actually taken forward by one of the project partners (Vectura CCD, a UK-based product development company) to develop a new powder-based inhaler. The informatics element was not included in the device, however the impacts of the research could still be substantial and these are summarised below. Longer term, research has looked at integrating the informatics technology and patient diary concept into "smart" pill boxes.

Assessment of Economic Impact

The economic impact of the project can be assessed as follows:

- Development of a new powder-based inhaler

Development of a new powder-based inhaler

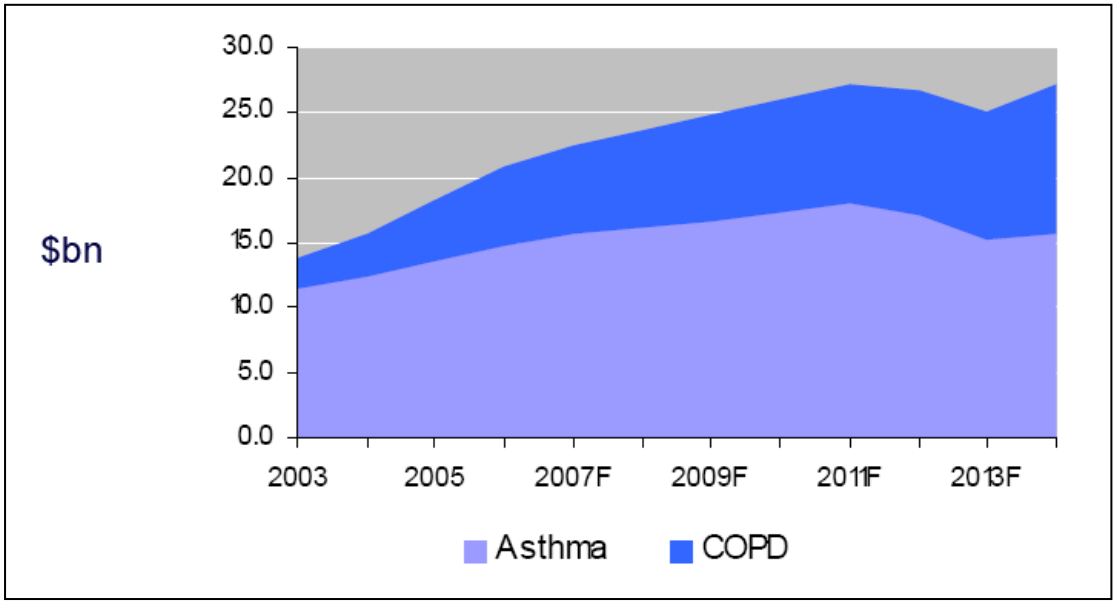
A non-disclosure agreement was in place between all partners for the majority of the lifetime of the e-medic project. This agreement also means that the name of the new inhaler is unavailable. However, an estimate can still be made of the potential market value using publicly available information on some of the products developed by Vectura.

In particular, in April 2010 two devices were highlighted to investors during a presentation made available on the London Stock Exchange website:

- **GyroHaler & Omnihaler**: Both are novel, pre-metered multi-dose, "passive" dry powder inhalers for effective local delivery of drugs into the lungs. The active pharmaceutical is packaged in blisters and it is suitable for the delivery of a wide range of respiratory drugs.

The size of the global respiratory market is huge and the worldwide annual sales figures for the most popular product, Advair/Seretide[24], were estimated to be just under $8 billion in 2009[25]. The total market is forecast to be worth around $26 billion in 2014 (see Figure 7) and could more than double in the next ten years[26].

Figure 7: Estimated size of the Global Respiratory Market, 2003-2014



Source: Vectura[27]

In 2008/2009, the top five products on the market accounted for nearly 80% of total sales. Assuming that this trend continues until 2014, the potential market for the two new Vectura products would be around $5.2 billion (20% of $26 billion). **Even if they only achieve market penetration of 1-2%[28], DTZ estimates that this would still equate to annual revenues of $52 million-$104 million (£33 million-£65 million[29]).**

Position without IMCRC Funding

The IMCRC funding for the E-Medic project was necessary to provide social benefits that are large in comparison to their private benefits. Such investment is known as a "public good" and in the case of this research project, could result in improved drug delivery for asthma suffers in the UK, for example. There is little incentive for any individual company in the industry to bear the full investment of developing the technologies required for E-Medic, taking into account the fact that success was not guaranteed.

---

[24] An oral inhaler that contains two types of asthma medication. One is fluticasone propionate, a steroid that reduces inflammation in the lungs. The other, salmeterol, is a long-acting bronchodilator that opens up the airways.

[25] http://www.londonstockexchange.com/companies-and-advisors/news-events/ukevents/gcid2010/vectura-presentation.pdf

[26] http://www.sharesmagazine.co.uk/node/5191

[27] Growing Companies Investors Day. April 2010. Available at: http://www.londonstockexchange.com/companies-and-advisors/news-events/ukevents/gcid2010/vectura-presentation.pdf

[28] The use of market shares is intended to provide an indicative view as to what the impact of the research could be. Where possible, the estimates have been verified with stakeholders.

[29] Figures converted using rate of $1=£0.63

Consultees

The following people were consulted and reviewed a draft of the case study:

- Professor Paul Conway, Loughborough University
- Professor Ron Summers, Loughborough University.

Case Study 4: Development of New Exercise Platforms

Key Facts	
Time Period	2003-2006
IMCRC Funding	£161,000
Other Funding	£128,000
Collaborator(s)	Progressive Sports Technologies Limited, Reebok Fitness Equipment, Playdale
IMCRC Research Theme	Next Generation Technologies
Research Output	The knowledge generated by the research was used in the design of a novel reconfigurable exercise platform (called Deck) and an outdoor play system (i-Play). Some of the research findings have also been used to inform the design of a product launched in 2010, the AB Pump.
Pathway to Economic Impact	Technologies developed by the research have been commercialised following IP protection and have been taken forward by Reebok Fitness and Playdale.
Actual Economic Impact	**Development of the Reebok Deck** – total revenues of £4.4 million **Development of i-Play** – total revenues of £1.5 million **IP revenue to spin-out** – £300,000 **Development of AB Pump –** total revenues to date of £1.2 million
Potential Economic Impacts	**Future sales of AB Pump** – DTZ estimates that if AB Pump achieves a market penetration of 0.5% in the UK sports equipment market, this would generate sales of £5.5 million **Future sales of i-Play** – DTZ estimates that over the next 2 years, i-Play could generate additional sales of between £750,000 and £1.5 million
Sector Focus	Healthcare

Context

The rationale behind the research undertaken at the IMCRC was focused on two main issues. **Firstly**, it was recognised that the perceived exertion level associated with a given exercise determines what effort people put in to that exercise. This raises the importance of being able to maximise the rate of calories burned whilst minimising the associated level of discomfort in order to optimise total calorific expenditure – i.e. striking the optimal balance between ideal weight loss and maintenance/cardiovascular benefit.

Secondly, the research was set against the backdrop of a growing problem of childhood obesity in the UK, where around 27.0% of children are now overweight and research suggests the main problem is a continual reduction in the amount of exercise children take[30]. Over the last twenty years obesity has trebled, and if trends continue it could become the number one cause of death in the next ten years:

- Half of all children could be obese by 2020[31]
- Overweight children are twice as likely to be obese when they grow up than children who are not overweight[32]

[30] http://www.bbc.co.uk/health/physical_health/conditions/obesity2.shtml
[31] http://news.bbc.co.uk/1/hi/health/5198154.stm
[32] http://www.bupa.co.uk/individuals/health-information/directory/o/child-obesity

- The economic cost of obesity in England is estimated at around £7.5 billion a year (House of Commons Select Committee, 2004).

To avoid an obese adult population and the associated economic and health problems this will create, experts recommend that physical education and activity are pursued and promoted in childhood. Stealth fitness has an important role to play in meeting this recommendation, as the higher the level of enjoyment, the less aware children are of the exertion required. Integrating exercise based play equipment into accessible environments enhances the physical play experience, getting children interested in exercise and keeping them interested.

The IMCRC Project

As part of the IMCRC project, different modes of exercise were explored using a bespoke machine to understand why different movement patterns burn calories at different rates. This allowed the perceived exertion level associated with a given exercise to be determined.

The new knowledge generated was utilised extensively in the design of a novel reconfigurable exercise platform (Deck) and solar powered outdoor play system (i-Play). Both technologies have been adopted by UK companies and commercialised following IP protection by a spin-out company at Loughborough – Progressive Sports Technologies Limited.

Assessment of Economic Impact

The economic impact of the project can be assessed as follows:

- Development of the Reebok Deck
- Development of i-Play
- IP income to Progressive Sports Technologies Limited
- Development of AB Pump

Development of the Reebok Deck

The original commercial collaborator, Reebok Fitness, secured the rights to exploit the intellectual property. The company tooled and manufactured a product that was subsequently launched as the Reebok Deck (see Figure 8). Reebok utilised their exisiting distributor network (including UK company, Escape Fitness) to sell the product in to health clubs around the globe. The Reebook Deck was laucnhed in March 2004 and **to date, more than 43,000 Reebok Decks have been sold (at an average price of £100), generating total revenues of around £4.4 million.** A home version has also been launched and this will generate further income.

Figure 8: The Reebok Deck

Development of i-Play

The i-Play product (see Figure9) was developed utilising the research findings gained from the original IMCRC funded project. Playdale, a UK playground equipment manufacturer, partnered the Loughborough team to take the concept to market and the product is manufactured in Cumbria.

Figure 9: i-Play

To date 60 units have been installed and approximately 850,000 games have been played across the UK. Costing £25,000 each, revenues generated for Playdale total £1.5 million. In addition, over the next 2 years the company expects to install between 30 and 60 new i-Play products and this would lead to additional revenues of between £750,000 and £1.5 million.

IP Income to Sports Technologies Limited

Both technologies have been adopted by UK companies and commercialised following IP protection. To date, IP income to the Loughborough University spin-out, Progressive Sports Technologies Limited, is £300,000.

Development of AB Pump

A number of the research outputs from the original IMCRC project have been applied to the development of a product launched in 2010. Called the AB Pump and developed in conjuntion with Reebok Fitness, the product is an upright abdominal exercise machine. According to information provided by Reebok Fitness, global sales figures for the AB Pump are in excess of 11,500 units[33]. Taking an average price of £100, total revenues generated to date are £1.2 million. Longer term, estimates on the potential economic impact can be made:

[33] Information provided by Reebok Fitness

- In a Key Note[34] report, the UK Sports Equipment Market was valued at £1.1 billion in 2008 – this figure represents direct spending on personal equipment by consumers and does not include expenditure by clubs or leisure centres

- Taking into account the recession and its impact on disposable income, Key Note forecasts that the UK market for sports equipment will decline in value in 2009 and 2010 but will then return to growth between 2011 and 2013.

Even if the UK sports equipment market remains at around £1.1 billion and AB Pump achieves market peneration of 0.5%[35], DTZ estimates that this would still generate sales of £5.5 million.

Position without IMCRC Funding

When assessing the economic impact of research it is important to consider the rationale for IMCRC investment in the research. The only rationale for IMCRC investment in research should be to address a market failure of some kind. In other words, there should be a reason why industry itself would not fund the research and why public intervention through the IMCRC is justified.

The private sector would be unlikely to invest in this type of research given the lack of information available on the certainty of a successful outcome and any subsequent product commercialisation. The IMCRC funding addressed this issue by supporting a multi-disciplinary research team from both the public and private sector. The social benefits of the project are large in comparison to their private benefits. For example, the products developed can ultimately benefit all of society by promoting healthier lifestyles and reducing obesity.

Consultees

The following people were consulted and reviewed a draft of the case study:

- Professor Mike Caine, Loughborough University

- Dr Phil Hodgkins, New Product Development Manager – RFE International

- Barry Leahey, Sales & Marketing Director – Playdale Playgrounds Limited.

[34] Key Note: Sports Equipment, 2009. (Key Note) is a supplier of marketing intelligence.

[35] The use of market shares is intended to provide an indicative view as to what the impact of the research could be. Where possible, the estimates have been verified with stakeholders.

Case Study 5: Design for Rapid (Additive) Manufacturing

Key Facts	
Time Period	2001-2003
IMCRC Funding	£317,000
Other Funding	£264,000 (Industrial contribution)
Collaborator(s)	3D systems INC Limited, Custom Design Technologies (formerly Bafbox Limited), Delphi Automotive Systems Limited, Microlise Engineering Limited, Rim-Cast, Huntsman (formerly Vantico Limited), Jaguar & Land Rover Group, MG Rover Group
IMCRC Research Theme	Next Generation Technologies
Research Output	The results of the research were disseminated in a number a ways, including journal publications, magazine articles and conference papers. The project was followed by further research entitled "Management of Rapid Manufacturing", which was funded by the former Department of Trade and Industry. Further projects have followed, a number of which have been supported by EPSRC as part of the IMCRC. This has helped to build Loughborough's profile as a leading centre for additive manufacturing research.
Pathway to Economic Impact	**Via collaborator(s) -** in the long term, it is likely to be industries such as the automotive sector and aerospace which implement the additive manufacturing techniques that will generate the most significant economic impacts.
Actual Economic Impact	The engineering tools created are still being trialled. The economic impacts are potential.
Potential Economic Impacts	**Reducing emissions in the aerospace sector:** If the additive manufacturing research being undertaken can support the UK in meeting future aircraft requirements and reducing their weight of these, the annual CO_2e savings could be worth £2.2 billion.
Sector Focus	Manufacturing

Context

There are two concepts that need to be understood in relation to the rapid (additive) manufacturing research:

- **Rapid Prototyping** is the collective name for a set of technologies and processes used to manufacture models directly from a 3D Computer Aided Design (CAD) model by constructively building them in layers. The processes include Stereolithography, Laser Sintering, Fused Deposition Modelling and 3-Dimensional Printing.

- **Additive, or rapid manufacturing** is the name given to the production of end-use parts or finished goods directly from virtual 3D CAD data and is an extension in use of rapid prototyping technologies into the wider manufacturing environment. The technology allows 3D objects to be created through the successive adding of material layer by layer. As well as creating existing geometries from less input materials it allows more complex geometries to be created[36].

[36] Sourced from: Advanced Manufacturing, 2009. Technopolis Group.

The main advantage of additive manufacturing processes is the ability to manufacture parts of virtually any complexity of geometry entirely without the need for tooling. However, when the original additive manufacturing project was developed, the Rapid Manufacturing Research Group at Loughborough University highlighted three areas that required research further investigation:

- Processes and Materials
- Design for Rapid Manufacture
- Organisation and Implementation.

The IMCRC Project

The IMCRC project was led by the Rapid Manufacturing Research Group at Loughborough and investigated how the advent of rapid manufacturing would affect the design and manufacturing of complex plastic components. It looked at the design opportunities afforded with the tool-less manufacturing of components by additive techniques and focussed on the following two areas:

Design Freedom

Freedom of design is one of the most important features of rapid/additive manufacturing and extremely significant for producing parts of complex geometry, which could result in reducing the lead-time and ultimately the overall manufacturing costs for such items. For manufacturers, costs could be dramatically reduced because no tooling is required and for customers, complex, individualised products could be cost effectively made that can be configured to personal use, thus giving the potential for much greater product satisfaction.

Each of the industrial partners was requested to nominate a part for redesign for rapid manufacturing. A total of four case studies were conducted during the two years and the ability of technologies to introduce features that are not possible to be manufactured by conventional means was determined. A set of guidelines for the design and assembly of additive manufacturing processes was established for designers.

Materials Properties

In order for designers to have confidence in selecting a material for a part to be designed for rapid manufacturing, they have to have extensive information regarding the properties of these materials. The project selected three materials and conducted extensive testing to investigate their mechanical properties.

To emphasise the importance of the research, it should be noted that the norm at the time was for design to stay within the constraints on traditional manufacturing technologies (for example, injection moulding) because additive techniques were largely confined to the prototyping of parts which would ultimately be mass-produced by traditional manufacturing technologies – hence the importance of research on processes and materials. Without this, there would not be the confidence in the ability of additive techniques to fabricate parts (rather than prototypes) for end use.

The results of the research were disseminated in a number a ways, including journal publications, magazine articles and conference papers. The project was followed by further research entitled “Management of Rapid Manufacturing”, which was funded by the former Department of Trade and Industry. Further projects have followed, a number of which have been supported by EPSRC as part of the IMCRC. The research programmes have all been developed to try and push forward the development and application of additive layer manufacturing technologies into main stream industrial applications.

One of the key outcomes from the original Design for Rapid (Additive) Manufacturing research has therefore been to act as a building block for subsequent research activities, facilitating strong linkages with industry and enhancing Loughborough's reputation as one of the leading centres for additive manufacturing research globally. The Rapid Manufacturing Research Group has since been named the Additive Manufacturing Research Group and significantly, Loughborough is the lead partner on a major Technology Strategy Board-funded project.

Called ATKINS, and involving industrial collaboration with partners such as Virgin Atlantic, Boeing, Delphi and Econolyst, it aims to address many of the issues currently preventing the techniques being used within the wider manufacturing community. The ultimate aim of the project is to utilize an additive manufacturing approach for metallic components in order to ensure the design, manufacture and distribution of fully optimized automotive/aerospace components are more sustainable with a significantly reduced carbon footprint.

Assessment of Economic Impact

The potential application of additive manufacturing is broad. Currently, one of its main uses is in the health sector for end-use components such as medical implants, hearing aids, dental crowns and surgical aids. In terms of its size, the overall market for dental crowns/caps is around $1.2 billion per year. Additive manufacturing accounts for only around 2% of this, or $24 million[37]. The most significant impacts are likely to be seen in the longer term, with research aiming to make additive manufacturing techniques viable on a larger scale for industries such as the automotive sector and aerospace – highlighted by the ATKINS project above.

If the research undertaken at Loughborough can help in overcoming the technical barriers to adopting the technology, it has the potential to make a significant impact on the UK economy. Taking into account the long term nature of the research and wide range of potential applications, the aerospace sector is discussed below as an example to provide an indicative view of the impact that additive manufacturing could have in the future.

Reducing emissions in the aerospace sector

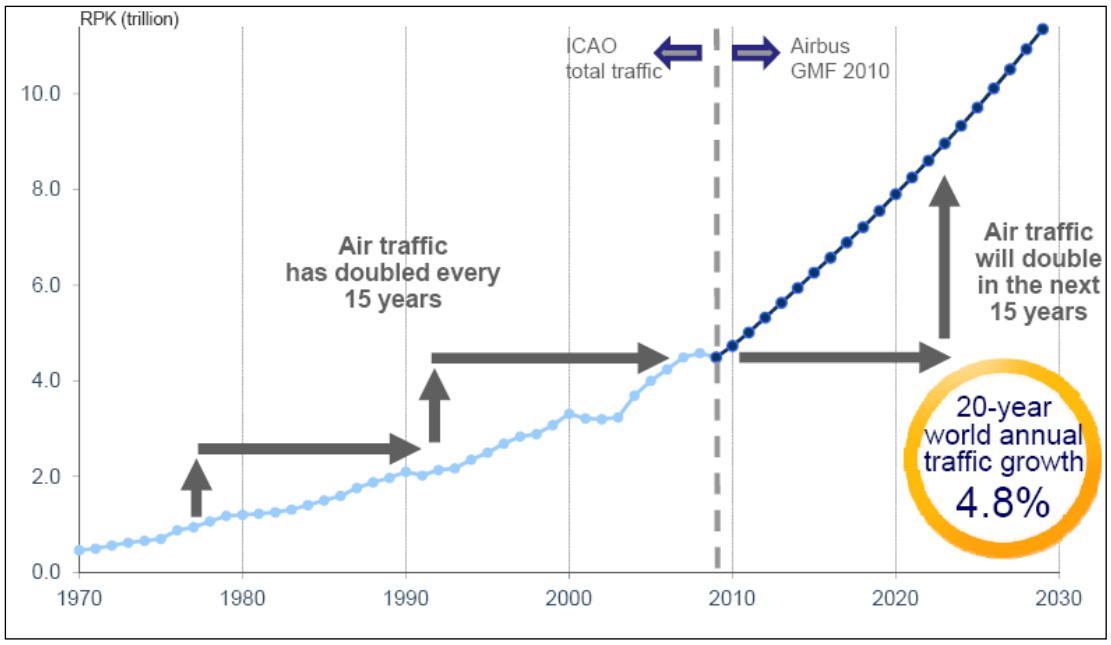
In the next 20+ years, revenue passenger kilometres[38] (RPK) are forecast to increase by 153% - from 4.76 trillion RPK in 2009 to 12.03 trillion RPK in 2029 (see Figure 10).

In order to accommodate this growth, it is estimated that more than 25,000 new passenger and freighter aircraft will be required. With a continuing focus on reducing the environmental impacts of flying, the additive manufacturing research has the potential to make a significant contribution to the sector by supporting the development of aircraft that are not only cheaper to make (because less raw materials are needed), but also lighter.

[37] Estimate provided by Econolyst, an additive manufacturing technology consultancy and collaborator on several of the additive manufacturing research projects undertaken at Loughborough.

[38] Calculated by multiplying the number of revenue-paying passengers aboard the vehicle by the distance travelled.

Figure 10: Long Term Forecasts for Revenue Passenger Kilometres, 2009-2029



Source: Airbus[39]

As an example:

- Of the 25,000 new aircraft required to accommodate long term passenger growth, the UK is estimated to account for 1,100[40]. The majority of these are likely to be short haul aircraft.

- If the weight of a short haul aircraft can be reduced by even 100kg, research published as part of the ATKINS study states[41] that this equates to savings over an aircraft's lifetime (taken to be 30 years) of 1Mt CO_2e.[42] The current valuation of this by DECC would be £60 million.[43]

Applying the £60 million value to the 1,100 aircraft required in the UK gives an overall saving of £66 billion. Taking into account the average aircraft lifetime of 30 years would give annual carbon savings equating to £2.2 billion. The research being undertaken on additive manufacturing at Loughborough is therefore vital if the UK is to reach a situation where it can support the adoption of new manufacturing techniques for industry.

Position without IMCRC Funding

Public sector intervention for the additive manufacturing research was necessary to provide social benefits that are large in comparison to their private benefits. Investment in the additive manufacturing research may ultimately benefit all of society through reduced costs and environmental impacts, for example.

---

[39] http://www.airbus.com/fileadmin/media_gallery/files/brochures_publications/Global_Market_Forecast/Airbus_Global_Market_Forecast_-_2010-2029.pdf

[40] http://www.guardian.co.uk/business/2008/feb/08/theairlineindustry.transport

[41] CO_2e = Carbon Dioxide equivalent – a standard measurement of greenhouse gas emissions

[42] Taken from: ATKINS: Manufacturing a Low Carbon Footprint – Zero Emission Enterprise Feasibility Study. October 2007. Estimated of 100kg used in the ATKINS study is modified from: Helms H. and Lambrecht U. (2006) "The Potential Contribution of Light Weighting to Reduce Transport Energy Consumption" International Journal of Life-Cycle Assessment.

[43] Assuming a carbon price of £60, Carbon Valuation in UK Policy Evaluation: a revised approach, July 2009, DECC.

In addition, the science and technology challenges which need to be overcome are of such scale and uncertainty (in terms of cost and time) that the potential payback period is beyond the timeframe for commercial investment. Without the guarantee of success, there is little incentive for any individual company in the industry to bear the full investment. The IMCRC funding supported not only the Design for Rapid (Additive) Manufacturing project, but has assisted in developing a wider strategic programme of research with industry that may not have existed otherwise.

Consultees

The following people were consulted and reviewed a draft of the case study:

- Professor Richard Hague, Loughborough University
- Dr Phil Reeves, Managing Director, Econolyst Limited
- Dr Ian Halliday, CEO, 3T RPD Limited
- Paul Smith, Lead Design Engineer, Delphi Diesel Systems.

Case Study 6: Business Driven Automation

Key Facts	
Time Period	2007-2011
IMCRC Funding	£702,000
Other Funding	£1.07 million
Collaborator(s)	Bosch Rexroth Corporation, Ford Motor Company, ThyssenKrupp Krause GmbH, Schneider Electric
IMCRC Research Theme	High Value Assets (70%) and Next Generation Technologies (30%)
Research Output	Development of new engineering tools and software to establish new business driven automation techniques in the automotive industry, which can be transferred across to other sectors.
Pathway to Economic Impact	**Via collaborator(s) -** Research outputs from the BDA project have been fast-tracked with Ford and trialled as part of "virtual build" events.
Actual Economic Impact	The engineering tools created are still being trialled. The economic impacts are potential.
Potential Economic Impacts	**Cost savings to the automotive sector -** At any one time, up to 10 engine programmes are being run. **Ford has estimated that the potential value of adopting the BDA approach to these programmes could be worth a total of £100 million**
Sector Focus	Automotive

Context

The market for the automation industry is changing rapidly with tougher competition and greater demand for higher quality products at lower cost and faster delivery to market. However, the extra cost of higher quality has to be supported by lowering unit production costs and optimizing resources. Existing automation systems can generally offer sufficient operational performance, however they can be difficult and complex to service, reconfigure, integrate, and optimise, particularly in the face of rapid, and often unforeseen, business change.

To date, high value manufacturing industries have applied limited automation because of the highly skilled nature of the finishing, inspection and assembly work required in manufacturing processes. It is extremely challenging to automate these processes because of minor variations in components that influence interaction between the processing equipment and the component being processed. In addition, parts are often made from expensive materials with many requiring careful handling.

High value industries need an advanced type of automation that delivers the precision of computer controlled machinery with the adaptability of a human operator. 24/7 capabilities are required, in addition to 100% quality performance and delivery at reasonable cost and operational speed.

These issues are especially relevant to the automotive sector and for companies in relation to power train assembly machines. Work in the sector is increasingly being undertaken in emerging markets such as India, Mexico and Brazil. Given the distances and timescales involved in travelling to these markets, the capability to undertake virtual engineering is becoming ever more important. There is also only a small resource available to undertake manual installation, therefore it becomes beneficial if the process can be done remotely.

The Business Driven Automation (BDA) project was therefore developed to establish a new, end-user, business-driven approach to automation systems development and support for the automotive sector.

The IMCRC Project

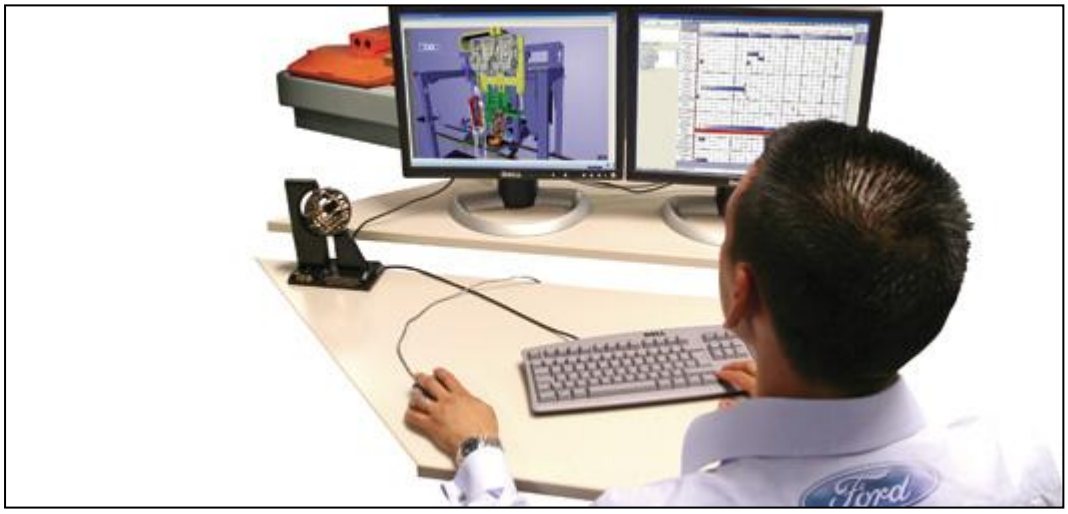
The BDA project has taken a generic approach in order to be applicable to virtually all automation sectors, although it is primarily targeting applications in automotive engine assembly. The IMCRC is working closely with a number of industrial partners such as Ford. The aim of the project is to help the sector evolve in a global context and be more internationally competitive. Significantly, it built on other work undertaken involving the partners on the BDA projects in various combinations. This included research that started in July 2007 in conjunction with Ford and Schneider Electric and focused on areas such as assessing the potential for new, more efficient, service relationships, roles and responsibilities in the automation supply chain underpinned by the use of Web services.

The initial work undertaken on the BDA project involved gaining an understanding of the underlying business processes in the automotive supply chain, setting up the necessary software development capabilities and test rigs. In 2009 new modules for the Ford India assembly line were modelled with the prototype BDA engineering tools via collaboration with Krause, a tier-one supplier to Ford of assembly machines and services, one of the other partners on the project.

An important part of the project involved carrying out a detailed study at Ford of their engineering process for all phases of the engineering of power train assembly machines. A similar exercise has been undertaken at Krause in order to understand the perspective of the machine builder supplying machine modules to meet end-user requirements.

Promising research outputs from the BDA project have been fast-tracked with Ford and this has involved demonstrating them with Ford engineers. In addition, the new engineering tools created have been demonstrated to the engineering teams at Ford as part of their “Virtual-Build Events”. This is where the various stages of engine build are evaluated digitally, prior to constructing the actual production system (see Figure 11).

Figure 11: BDA Software Trial



Assessment of Economic Impact

The economic impact of the project can be quantified as follows:

Cost Savings to the Automotive Sector

From an economic perspective, the BDA project has the potential to generate significant cost savings for the automotive sector. The tools are being developed so that they are capable of being used throughout the machine lifecycle, not just at initial build. Moreover, one of the main deliverables will be an automation resource library for previously developed virtual systems. These can then be used as a standard template in the future so that engineers do not have to completely re-engineer a machine.

The 2009 Loughborough IMCRC Annual Report highlighted that the economic value of the proposed BDA approach was estimated by Ford to be worth up to £20 million for a major new engine programme. At any one time, up to 10 engine programmes are being run. Not all of these will be classified as being major, **however the consultation exercise undertaken to inform this case study revealed that the company has estimated the potential value of adopting the BDA approach to these programmes could be worth a total of £100 million**. The economic benefits could be higher than this if the BDA system is utilised by companies in the wider supply chain.

Position without IMCRC Funding

For this project, the outcomes of the research were uncertain and industry would not have been prepared to pay the full costs associated with it. The scope of the research meant that industry and academia needed to work together in order to fully test whether new business driven automation engineering processes could be developed. The IMCRC funding helped by funding the academic expertise, which was supported by cash and in-kind contributions from industry. The potential economic benefits of the project are clear and as the research has developed over time, outputs have been tested by industry to ensure the most effective benefits are being delivered.

Consultees

The following people were consulted and reviewed a draft of the case study:

- Professor Rob Harrison, Loughborough University
- Dr Leslie Lee, Manufacturing Engineering – Powertrain Operations. Ford Motor Company.