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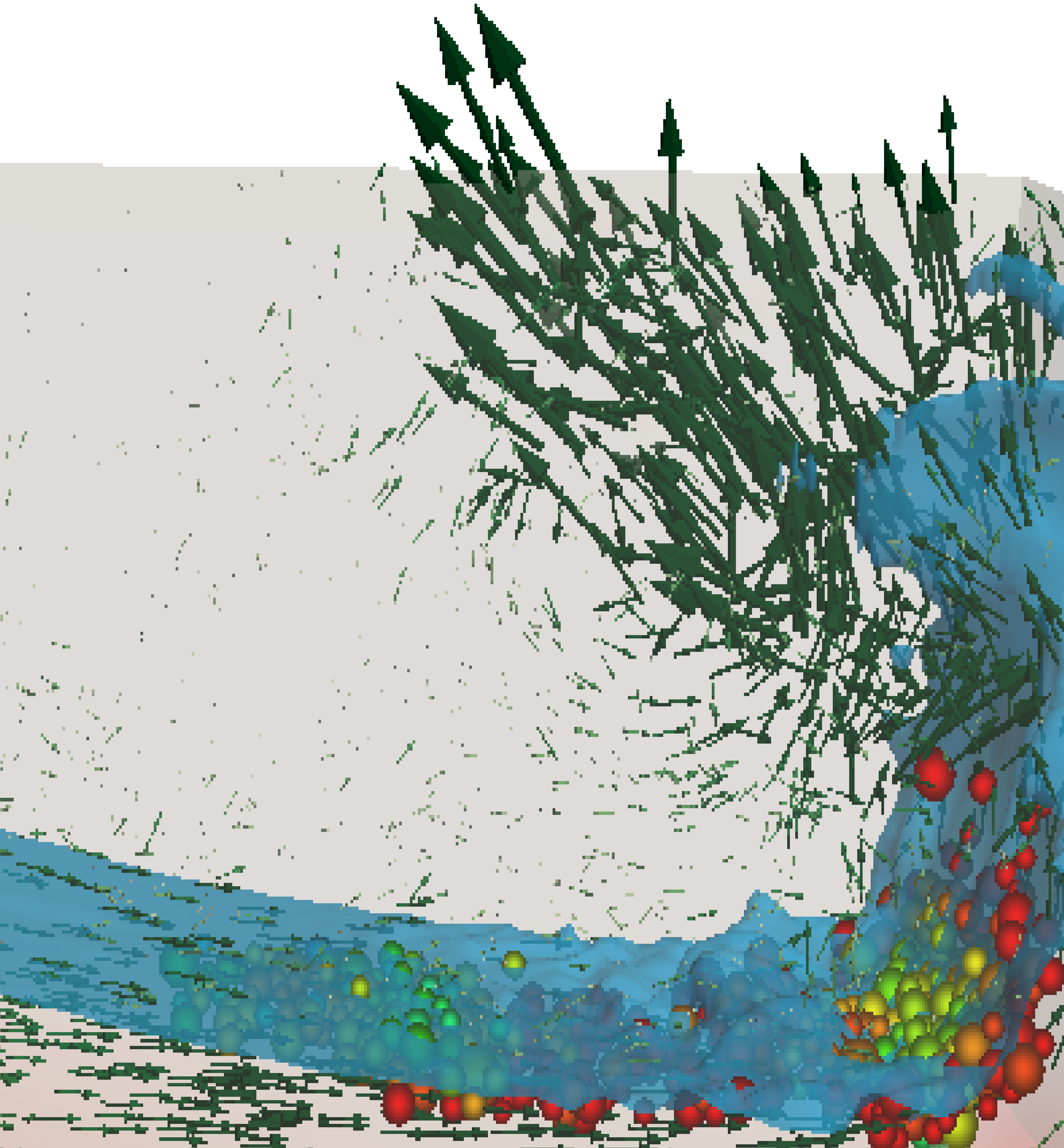

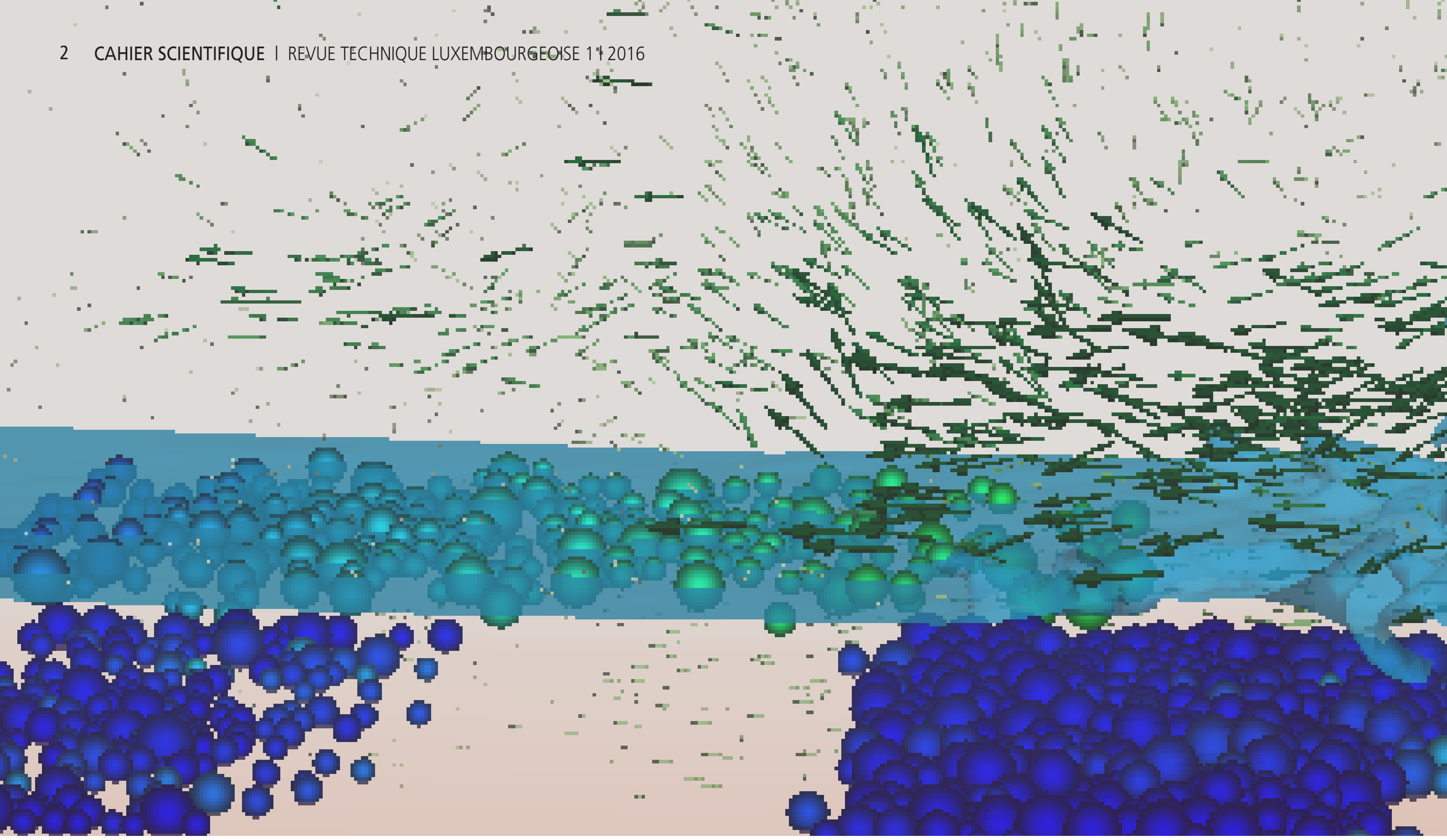

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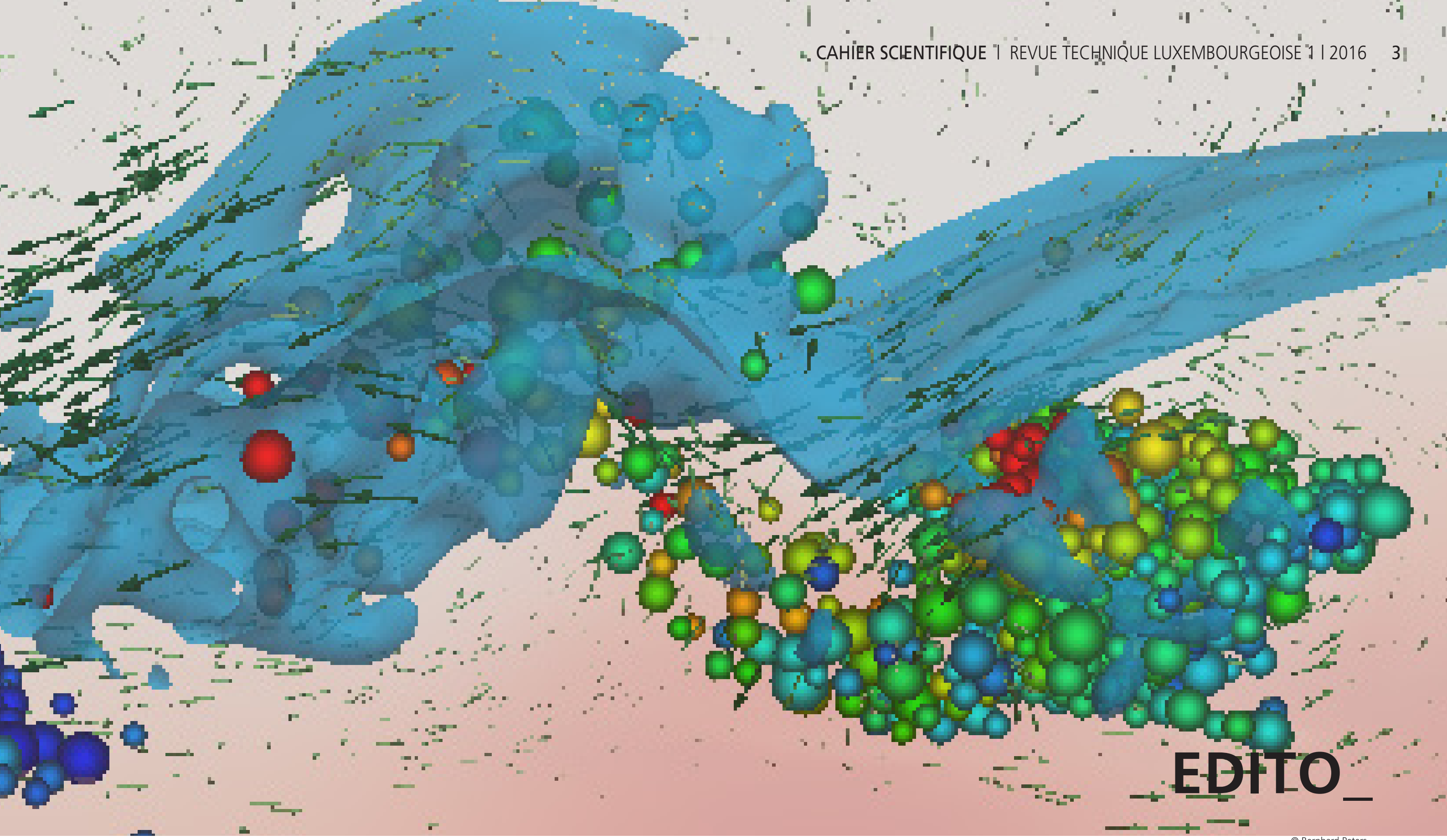





Seit 1916 werden in Luxemburg Ingenieure ausgebildet, womit die heutige Research Unit in Engineering Science (RUES) auf die längste Tradition im enseignement supérieur im Land blickt.

Exakt vor hundert Jahren, im September 1916, wurde der erste «Cours technique du supérieur» angeboten, der später in das Institut Supérieur de Technologie, IST, überging. Das Lehrangebot erweiterte sich mit der Gründung der Universität im Jahre 2003 um die ingenieurwissenschaftliche Forschung. Inzwischen lehren und forschen hier zahlreiche international anerkannte Universitätsprofessoren, denen die 100-jährige Tradition Verpflichtung und Ansporn zugleich ist.

Die ständige Verbesserung der Lehrqualität und Erweiterung um die wissenschaftliche Forschung in ausgewählten Bereichen führte zu weltweiter Aufmerksamkeit und Anerkennung der im Land erbrachten Leistungen. Die zunehmende internationale Reputation zeigte sich unlängst im guten Ranking von Times Higher Education, THE, welche die Universität als eine der besten Neugründungen evaluierte sowie im Vergleich der etablierten Universitäten bereits mit einen Platz unter den TOP 200 von 800 weltweit einstufte, vor den anderen Universitäten der Großregion, wie bspw. Kaiserslautern oder Liege.

Die RUES erforscht Technologien, die heute noch nicht bekannt sind, vermittelt dieses Wissen in der Lehre an die nächste Generation Ingenieure, und versetzt sie so in die Lage, neue Technologien zu entwickeln, zu optimieren und anzuwenden. Die akademische Ausbildung wird durch das Angebot an berufsbegleitender Fortbildung ergänzt. Ein wichtiger Schwerpunkt der Ausbildung an der Universität liegt auf nachhaltiger, ressourceneffizienter Technologie und allem, was unter dem Themenkomplex vernetzte Systeme bzw. Industrie 4.0 zusammengefasst wird.

Lehre und Forschung gehen dabei Hand in Hand. Zukunftsorientierte Ingenieursausbildung vermittelt breit angelegtes, solides Methodenwissen. Dann kann der Absolvent später im Berufsleben neu aufkommende Technologien erkennen, aufgreifen, weiterentwickeln und zum wirtschaftlichen Vorteil des Unternehmen einsetzen.

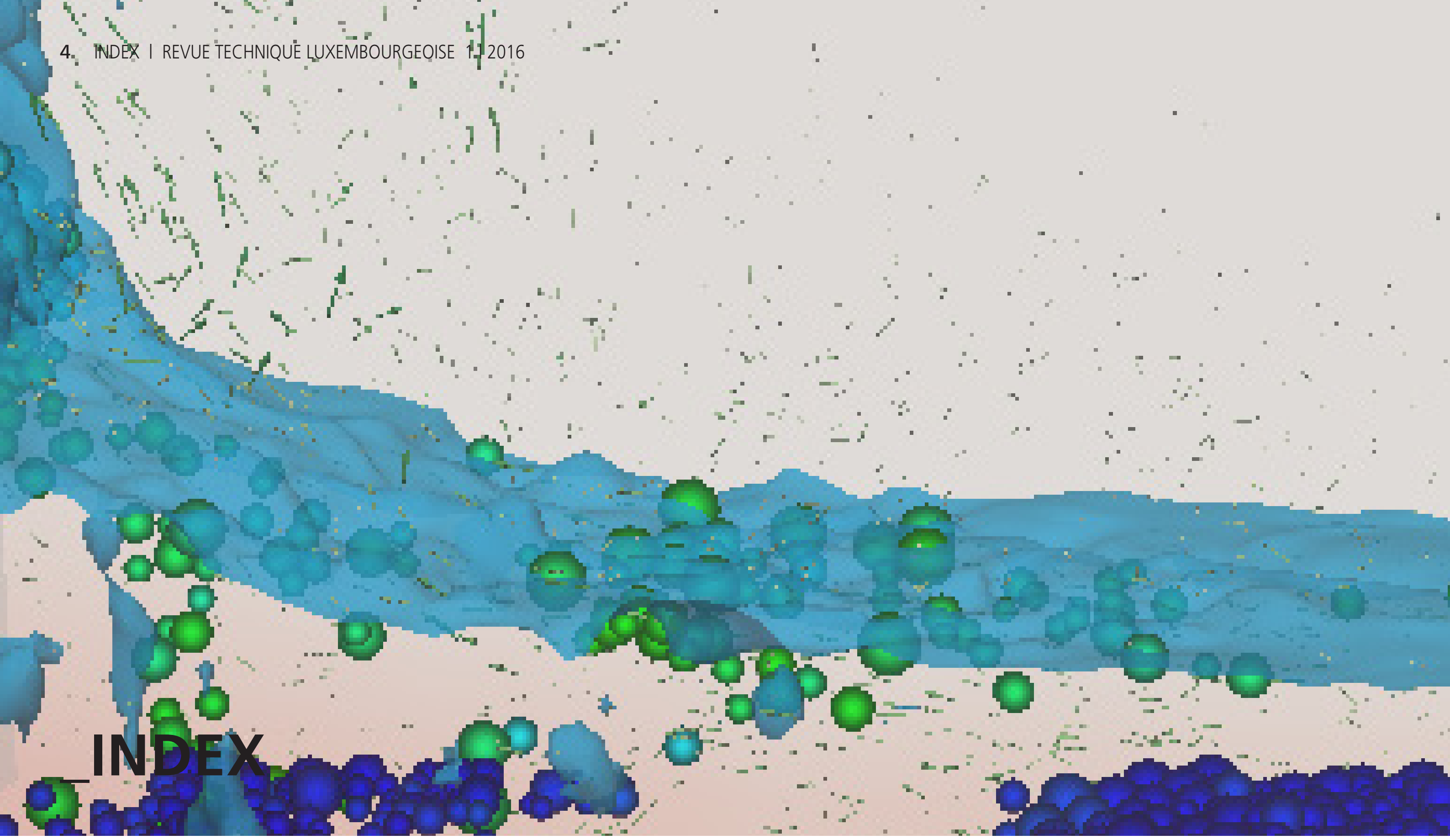
Ausbildung in neuen Technologien schafft Arbeitsplätze. So stehen inzwischen auch asiatische Produktionswerke unter dem Druck, die Kosten zu senken. Sie versuchen durch strategische Beteiligungen, bspw. an europäischen Roboterherstellern, sich den Zugang zur erforderlichen Technologie zu sichern. Passend dazu kündigt Adidas an, seine manuelle Produktion aus China zurückzuholen und in der bayerischen Provinz eine „Hochgeschwindigkeitsfabrik" zu etablieren.

Industrieroboter tragen dazu bei, nicht- ergonomische Arbeitsplätze zu vermeiden. Dazu ist das automatische Nachfahren von dreidimensionalen Freiformflächen mit intelligenten Robotern ein erster, wichtiger Schritt. Die Echtzeitregelung technischer Prozesse ermöglicht Innovationen in der Produktion und Steigerung der Wertschöpfung im Land. Auch High Performance Computing, HPC, hat großes Potential, das noch nicht vollständig gehoben ist, wie beispielsweise die hier beschriebene Simulation von Treibgut im Hochwasser.

Lesen Sie in diesem Heft die Bestandsaufnahme des ICT-Ökosystem des Landes, wie medizinische Apps Ihre Daten sammeln und welche Auswirkungen Industrie 4.0 auf den Arbeitsmarkt hat.

Die Universität trägt mit hervorragend ausgebildeten Ingenieuren und hochwertiger Forschung zur Sicherung der Wettbewerbsfähigkeit, zur Steigerung der Profitabilität und letztendlich dem Steueraufkommen bei. Damit schließt sich wieder der Kreis zur bereits erwähnten Lehre und Forschung, die ja schlussendlich auch finanziert werden muss - Ingénierie - zanter 1916.

Prof. Dr.- Ing. Peter Plapper



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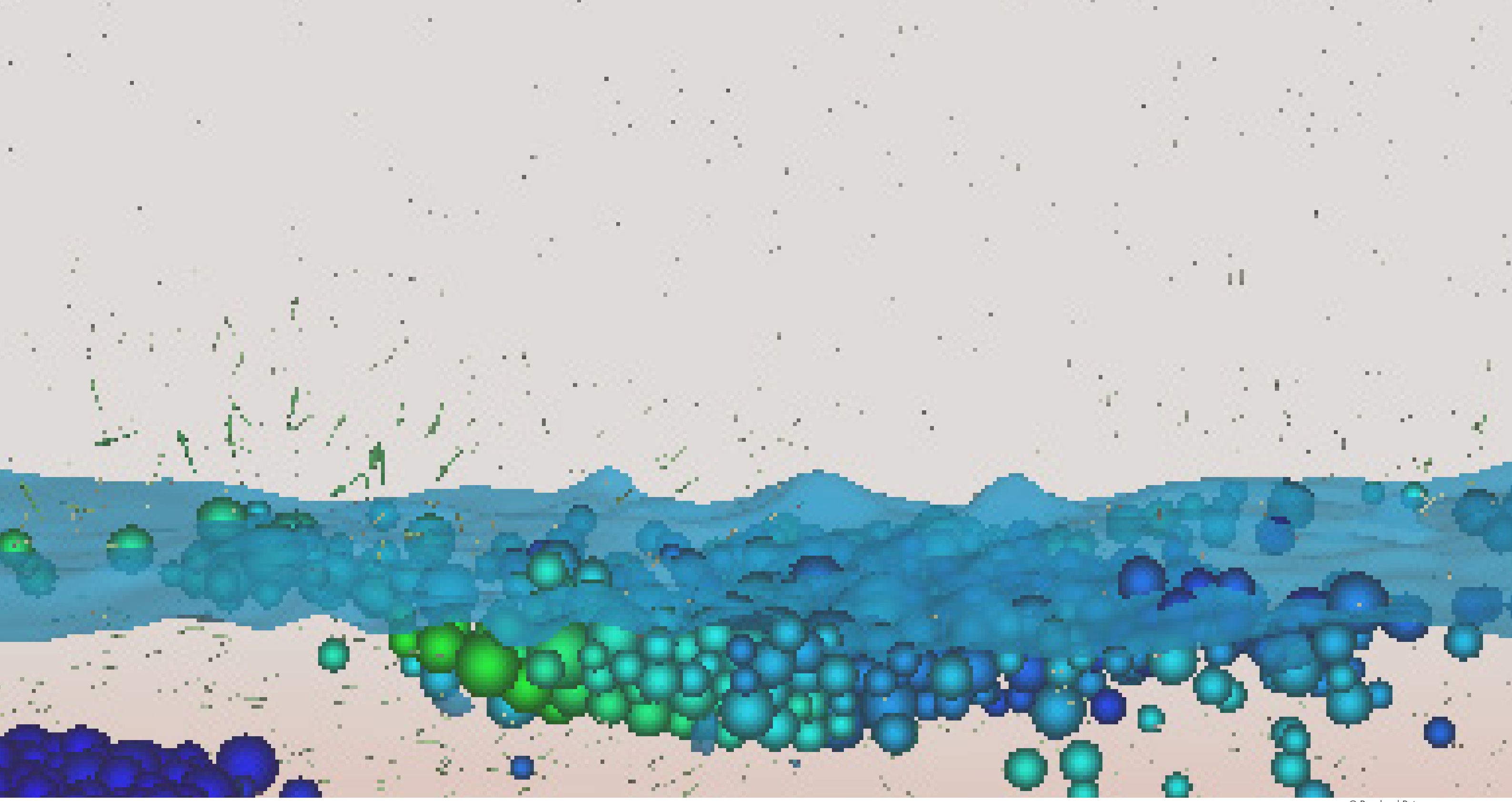

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Unergonomic working conditions, a decline in available labour force and uncompetitively high salaries make automation an attractive solution for a variety of manufacturing processes. To achieve successful automation of even complex, contact-based manufacturing processes, inspiration is more and more found in nature. In this work, a biomimetic approach is chosen to address the grinding process of freeform geometries by industrial robots.

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# TRAJECTORY TRACKING FOR ROBOTIC FREEFORM GRINDING_

Sophie Klecker, Doctoral Candidate, Prof. Dr.-Ing. Peter Plapper

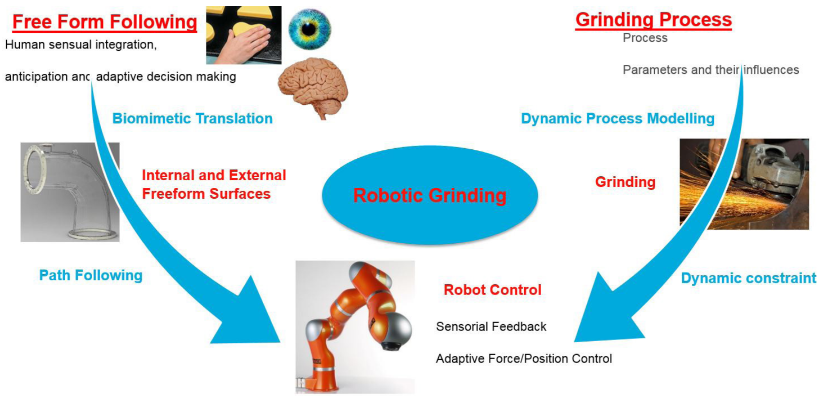



_Figure 1: comprehensive challenge: Robotic Grinding, an interplay of free form following and grinding process

This research work is part of the discipline of manufacturing engineering and more precisely of the automation of production processes.

Hazardous environments and arduous work lead to an increasing lack in skilled and motivated labour force in manufacturing industry. This fact in combination with uncompetitively high manpower costs in Luxembourg make automation a promising option to keep production in the country while enhancing competitiveness through constant quality-levels and predictable production times.

A challenge, as uttered by industry, is the desire to use robotic manipulators for contact-based surface treatments on complex 3dimensional geometries. Indeed, the industrial state-of-the-art still uses human workers instead of robotic manipulators for these non-ergonomic processes. A special focus is put on automating the grinding of internal and external freeform surfaces.

Biomimetic research aims for human-made solutions mimicking biological solutions, taking advantage of the strength of natural evolution. Applied to the automation of the grinding process, this means analyzing the human way to perform the task, to grind a freeform surface.

Besides a good idea of the global process and its critical points, the human analogy allows to divide the process into two subprocesses: freeform following and grinding. In order to perform robotic grinding, first the surface at stake is followed and then the grinding force is added to remove the required amount of material before both subprocesses are integrated and extended by robotic control. The interplay of these subparts is shown in Figure 1.

In a first phase the focus lays on the left half of Figure 1: the following of freeform surfaces and the related robotic control. For the specific use case, different surface following scenarios that could occur in the case of a freeform grinding process are investigated and the control strategy is adapted to the respective circumstances.

Freeform grinding requires constant contact between workpiece and tool, repetitive processing of the same surface, reciprocating motion, where applicable taking into account a certain depth of cut, switching between different surfaces and uncertainties from different sources. The latter are both system-inherent, including unknown robot dynamics and parameters and environmental uncertainties.

A benchmark-trajectory which is considered is a convex path followed by a jump-switch to the same convex path, shifted by the intended depth of cut. Figure 2 illustrates the desired movement of the end-effector of the robotic manipulator.

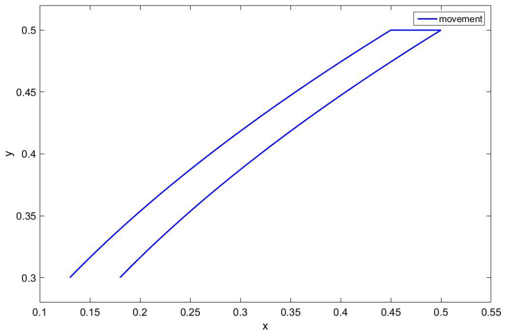



_Figure 2: desired end-effector movement in the x-y-plane

The addressed problem, covers a subpart of the comprehensive problem, freeform grinding, namely the control of a trajectory tracking industrial robotic manipulator with switching constraints. The dynamics of the constrained robotic manipulator are represented in the form of the following equation:

$$\ddot{q} = M^{-1}(q)[\tau - V(q,\dot{q})\dot{q} - G(q)] \qquad (1)$$

With *M(q)* the robotic manipulator inertia matrix, *V* the Coriolis matrix, *V(q,q)q* the centrifugal and Coriolis vector, *G(q)* the gravity vector, control moment $\tau$ is the vector of actuator torques and vector *q* giving the positions of the links. A sliding mode control scheme, which is extended with an adaptive parameter update law to account for parameter-uncertainty is applied.

The following control torque is suggested:

$$\tau = M(q)\left(-\tau_s + \ddot{q}_d + b\dot{e} + M^{-1}(q)\big(V(q,\dot{q})(\dot{q}_d - ae) + G(q)\big)\right) \qquad (2)$$

Where *a* and *b* are positive constants and

$$\tau_s = sat(s)c + s \qquad (3)$$

With *c* being *a* vector relating to the bound of the trajectory-function and

$$sat(s) = \begin{cases} sign(s) & if |s| > \Delta \\ \frac{1}{\Delta}s & otherwise \end{cases} \qquad (4)$$

where $\Delta$ represents the boundary layer.
And the chosen sliding variable

$$s = \dot{e} + \vartheta e \qquad (5)$$

Where $q_d$ is the desired position, $\vartheta$ is a positive diagonal matrix and e is the tracking error, defined as the difference of the actual position and the desired position. Because parameter *c* is of highly uncertain nature, the implementation of a parameter update law is suggested. The following update law was introduced by [1]:

$$\dot{c} = \begin{cases} p|s| & if\ |c| < \tilde{c}\ or\ |c| = \tilde{c}\ and\ p|s| \le 0 \\ p|s| + \frac{p|s|\tilde{c}^T\tilde{c}}{|\tilde{c}|^2} & if\ |c| = \tilde{c}\ and\ p|s| > 0 \end{cases} \qquad (6)$$

where *p* is a constant and $\tilde{c}$ is an estimate of c.

**Reference:**

[1] Jasim I.F., Plapper P.W., Adaptive Sliding Mode Control of Switched Constrained Robotic Manipulators, 2013 11th IEEE International Conference on Industrial Informatics (INDIN), 305-310.

https://commons.wikimedia.org/wiki/File:Eye_I.jpg (22.10.2015)

http://www.welcomemobility.co.uk/images/products/medium/HC_091048776.jpg (22.10.2015)

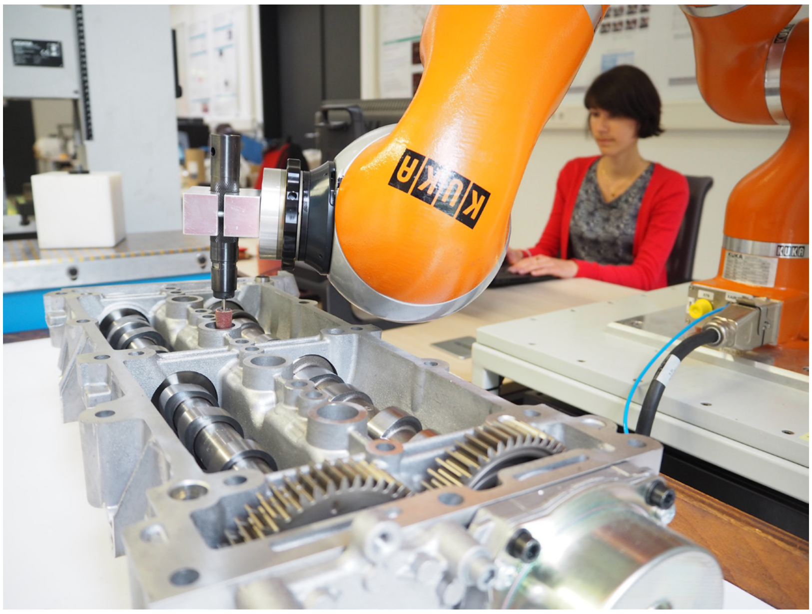
http://www.thenanoage.com/cryonics.htm (22.10.2015)

https://grabcad.com/library/90-degree-taper-pipe (28.09.2015)

https://commons.wikimedia.org/wiki/File:Grinding_Sparks_-_Kolkata_2011-11-26_7427.JPG (22.10.2015)

http://www.metal-supply.com/announcement/view/7193/kuka_roboter_is_presenting_a_new_robot_generation_at_automatica_2010#.Vgkr5RvouUk (28.09.2015)

A similar version of this work is presented at the 14th International Conference on Industrial Informatics in Poitiers, France 18-21 July 2016



The stability of the suggested control scheme can be proven by Lyapunov theory.The validity of the suggested scheme is demonstrated by a simulation of a planar 2-link robot in MATLAB/SIMULINK. The 2-link robot follows the path shown in Figure 2 while applying the discussed adaptive sliding mode strategy over a period of 20s. Figures 3 and 4 show the simulation results, the position tracking of the first and the second link, respectively.
The obtained results show a good correspondence between ideal signals and tracking signals.

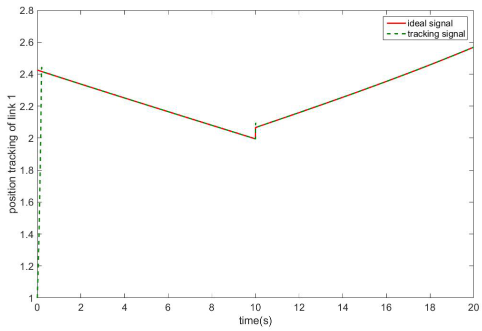



_Figure3: position tracking of link 1

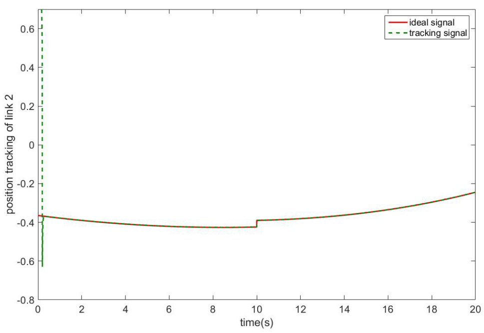



_Figure4: position tracking of link 2

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Die neueste Welle des technologischen Fortschritts wird intensiv unter dem Namen Industrie 4.0 diskutiert. Nach den bisherigen industriellen Revolutionen geht es dabei um die Vernetzung der virtuell-digitalen und physischen Welt sowie um maschinelles Lernen in der Produktion. Einbezogen werden Maschinen, Produkte, Informations- und Kommunikationssysteme sowie der Mensch. Ziel ist, dass Wertschöpfungsketten vollständig digital gesteuert werden bzw. sich selbstorganisiert steuern können. Eine effizientere, flexiblere und individuellere Produktion soll das Ergebnis sein.

# INDUSTRIE 4.0 - WIRKUNGEN AUF WIRTSCHAFT UND ARBEITSMARKT_

Prof. Dr. Enzo Weber

Wie die Zukunft der Arbeit unter diesen Bedingungen aussehen wird, ist umstritten:
Die einen befürchten massenweise Jobverluste, wenn heutige Berufe durch vernetzte Roboter überflüssig gemacht werden, die anderen zeigen Glanzbilder von großen Beschäftigungs- und Innovationsgewinnen sowie eine Entlastung der Arbeitnehmer auf.

Technologischer Fortschritt ist so alt wie die Menschheit, und zumindest bisher ist die Arbeit nicht ausgegangen. Natürlich, nur allzu leicht tendiert jede Generation dazu, das vor ihr Liegende als qualitativen Sprung zu deuten, der alle bisherigen Gesetze und Reaktionsmuster obsolet macht. Einerseits liegt man damit aber regelmäßig falsch. Oder meinen wir wirklich, dass der technologische Fortschritt gerade jetzt damit beginnt, Arbeit massenhaft zu reduzieren, während er das über Jahrtausende nicht getan hat?

Andererseits darf man es sich aber auch nicht zu leicht machen: So ging der Wandel weg von herkömmlicher Fabrikarbeit seit den 1970er Jahren mit einem starken Aufbau struktureller Arbeitslosigkeit vor allem von Niedrigqualifizierten einher. Dieser Gegensatz zeigt vor allem eines: Für eine umfassende Bewertung der ökonomischen Wirkungen von Industrie 4.0 ist eine Vielzahl von Effekten zu berücksichtigen; das Verschwinden von Arbeitsplätzen ebenso wie die Schaffung von neuen, Wandlung von Anforderungen, effizientere Prozesse und neue Produkte, volkswirtschaftliche Kreislaufzusammenhänge, Anpassungen von (Arbeits-)Angebot und Nachfrage, Preis- und Mengenreaktionen.

In einer Studie des Instituts für Arbeitsmarkt- und Berufsforschung, des Bundesinstituts für Berufsbildung und der Gesellschaft für wirtschaftliche Strukturforschung wurde das komplexe gesamtwirtschaftliche Q-INFORGE-Modell für eine Industrie-4.0-Szenarioanalyse verwendet. Das Modell bildet eine umfassende Makroökonomie und einen detaillierten Arbeitsmarkt ab, wobei Arbeitsangebot und -nachfrage nach Branchen, Berufen und Qualifikationen gegliedert werden.

Funktionaler Kern ist ein Matchingmodul, das berufliche Flexibilitäten zulässt sowie Rückwirkungen über Lohn- und Preisreaktionen generiert. Das Szenario soll über zahlreiche Komponenten wie Investitionen, Produktivität, Berufe und Tätigkeiten sowie Nachfrage Industrie 4.0 ökonomisch erfassen.

In der Szenarioanalyse ergibt sich eine zunehmende Wertschöpfung, die bei steigender Produktivität und höheren Anforderungen an die Arbeitnehmer vor allem in einer wachsenden Lohnsumme resultiert. Beim Beschäftigungsbestand zeigen sich keine wesentlichen Änderungen; in der Summe ist Industrie 4.0 also weder eine Jobmaschine noch eine Beschäftigungsvernichterin.

Dahinter kommt es allerdings zu deutlichen Bewegungen: In den aus 54 Berufsfeldern und 63 Wirtschaftszweigen bestehenden Zellen gehen innerhalb von zehn Jahren über das Basisszenario hinaus 490 000 Arbeitsplätze verloren, während anderweitig 430 000 neu geschaffen werden. Vor allem Berufe im produzierenden Bereich verlieren, beispielsweise Maschinen bedienende Berufe. In einer Reihe von Berufshauptfeldern und speziell bei Dienstleistungen gibt es dagegen Gewinne, die höchsten bei IT- und naturwissenschaftlichen Berufen.

Bezogen auf Qualifikationsstufen gewinnt der akademische Bereich, die wesentlichen Verluste treten im Bereich der mittleren Qualifikationen auf. Auch die Nachfrage nach Niedrigqualifizierten geht zurück. Insgesamt zeigt sich, dass die Wirkung von Industrie 4.0 sogar zu einem gewissen Ausgleich der sich im Basisszenario abzeichnenden Ungleichgewichte führen kann: Engpässe bei den Ausbildungsberufen der Industrie werden tendenziell gemildert. Für das stark steigende Angebot im akademischen Bereich wird dagegen zusätzliche Nachfrage generiert. Für eine Wirkungsanalyse der Arbeitsmarktentwicklung muss neben den die Debatte beherrschenden Änderungen des Arbeitskräftebedarfs also auch die Entwicklung des Arbeitskräfteangebots mitgedacht werden.

Dieses scheinbar so beruhigende Ergebnis soll aber keine Entwarnung signalisieren. Die schwierige Arbeitsmarktsituation von Geringqualifizierten wird sich nach den Ergebnissen tendenziell noch verschlechtern. Wenn in diesem Bereich auch Impulse beispielsweise durch den Einsatz von Assistenzsystemen denkbar sind, wächst wohl doch die schon bestehende Notwendigkeit arbeitsangebotsseitiger Maßnahmen.

Hinter den gesamtwirtschaftlichen Wirkungen des Phänomens Industrie 4.0 stehen auf betrieb-licher und politischer Ebene bedeutende Herausforderungen. Schließlich sind erhebliche Verschiebungen und Veränderungen von Arbeitsplätzen absehbar.

Eine zentrale Rolle kommt dabei Bildung und Weiterbildung zu. Es liegt nahe, auf eine Stärkung digitaler Inhalte zu verweisen, aber mindestens ebenso wichtig wird es sein, Kompetenzen wie konzeptionelles Denken, Abstraktions- und Kommunikationsfähigkeit zu vermitteln.

Bei sich ändernden und erhöhten Anforderungen wird nach der Erstausbildung die Weiterbildung entscheidend werden, um Kompetenzen laufend weiterzuentwickeln. Hier kommt es auch darauf an, die gerade in Deutschland deutlich sichtbaren Vorteile formaler Qualifikation mit flexiblem Kompetenzerwerb zu verbinden. Koordinierte Anerkennung von zusätzlichen Qualifizierungsleistungen ist ein Weg dahin.

Industrie 4.0 als Prozess, in dem durch die Digitalisierung neue Tätigkeitsprofile entstehen, muss im internationalen Wettbewerb aber auch entsprechend der eigenen Stärken angegangen werden. So richtig ein wachsender Fokus auf die Hochschulausbildung ist, so klar liegen spezifisch deutsche Stärken im berufsbildenden System und seiner Verzahnung von Theorie und Praxis.

Eine aktive - und nicht nur reaktive - Politik entwickelt diese Stärken gezielt weiter, um Menschen auszubilden, die die Umsetzung von Industrie 4.0 formen können. Wenn Produktions-, Wissens- und Entwicklungsarbeit weiter zusammenwachsen, ergeben sich neue Felder, in die auch der berufsbildende Bereich hineinwachsen kann. Denkbar ist, die Attraktivität in einem «Meister-tenure-track» durch einen integrierten Ausbildungsweg bis zum Meister zu erhöhen und diesen Grad mit weiteren Kompetenzen zu stärken.

Auch die Arbeitsmarktpolitik muss sich auf neue Entwicklungen einstellen. Derzeit liegt das Entlassungsrisiko auf einem Rekordtief, was den Arbeitsmarktaufschwung wesentlich begünstigt. Die Arbeitsmarktdynamik wird nach den Szenarioergebnissen aber deutlich zunehmen, und damit auch die Zugänge in Arbeitslosigkeit. Wenn sich der strukturelle und berufliche Wandel verstärkt, wird eine Weiter- und Neuqualifizierungsberatung essenziell.

Möglichst frühzeitig muss fundiert entschieden werden, ob eine Vermittlung im bisherigen Tätigkeitsfeld, eine Weiterentwicklung oder Neuorientierung der richtige Weg ist. Weitere Bereiche wie der Arbeits- und Gesundheitsschutz, die betriebliche Mitbestimmung, die soziale Sicherung und der Datenschutz werden sich neuen Herausforderungen gegenübersehen. Während das hier beschriebene Szenario auf die Industrie fokussiert ist, ergeben sich bereits jetzt auch für den Dienstleistungsbereich deutliche Effekte. Eine umfassende Untersuchung der Wirkung von Digitalisierung in der gesamten Wirtschaft (Wirtschaft 4.0) werden die Projektpartner im nächsten Jahr vorlegen.

www.iab.de

**Freigabe:**
Enzo Weber: Industrie 4.0 - Wirkungen auf Wirtschaft und Arbeitsmarkt, in: Wirtschaftsdienst, 95. Jg. (2015), H. 11, S. 722-723, © ZBW und Springer-Verlag Berlin Heidelberg, http://www.wirtschaftsdienst.eu/archiv/jahr/2015/11/industrie-40-wirkungen-auf-wirtschaft-und-arbeitsmarkt/.

Hochwasser hervorgerufen durch natürliche Ursachen wie Schneeschmelze oder durch bauliche Maßnahmen wie Flussbegradigung verursacht häufig eine Flutkatastrophe mit verheerenden Überschwemmungen. Zu den schon katastrophalen Folgen von Hochwasser addieren sich häufig noch die Schäden von gefährlichem Treibgut, das mit den Fluten mitgerissen wird und unter Umständen über weite Strecken transportiert wird. Mitgerissenes Treibgut kann zur Verklausung von Brücken führen oder auch Bauwerke zerstören. Um die Folgen eines Hochwassers einschließlich Transport von Treibgut abschätzen zu können, sind numerische Werkzeuge eine adäquate Ergänzung zu experimentellen Methoden, die oft mit einem sehr hohen Aufwand verbunden sind.

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# INNOVATIVE RECHNERISCHE METHODEN ZUM TRANSPORT VON TREIBGUT BEI HOCHWASSER_

Prof. Dr. - Ing. Bernhard Peters, Gabriele Pozzetti, Yu Liao

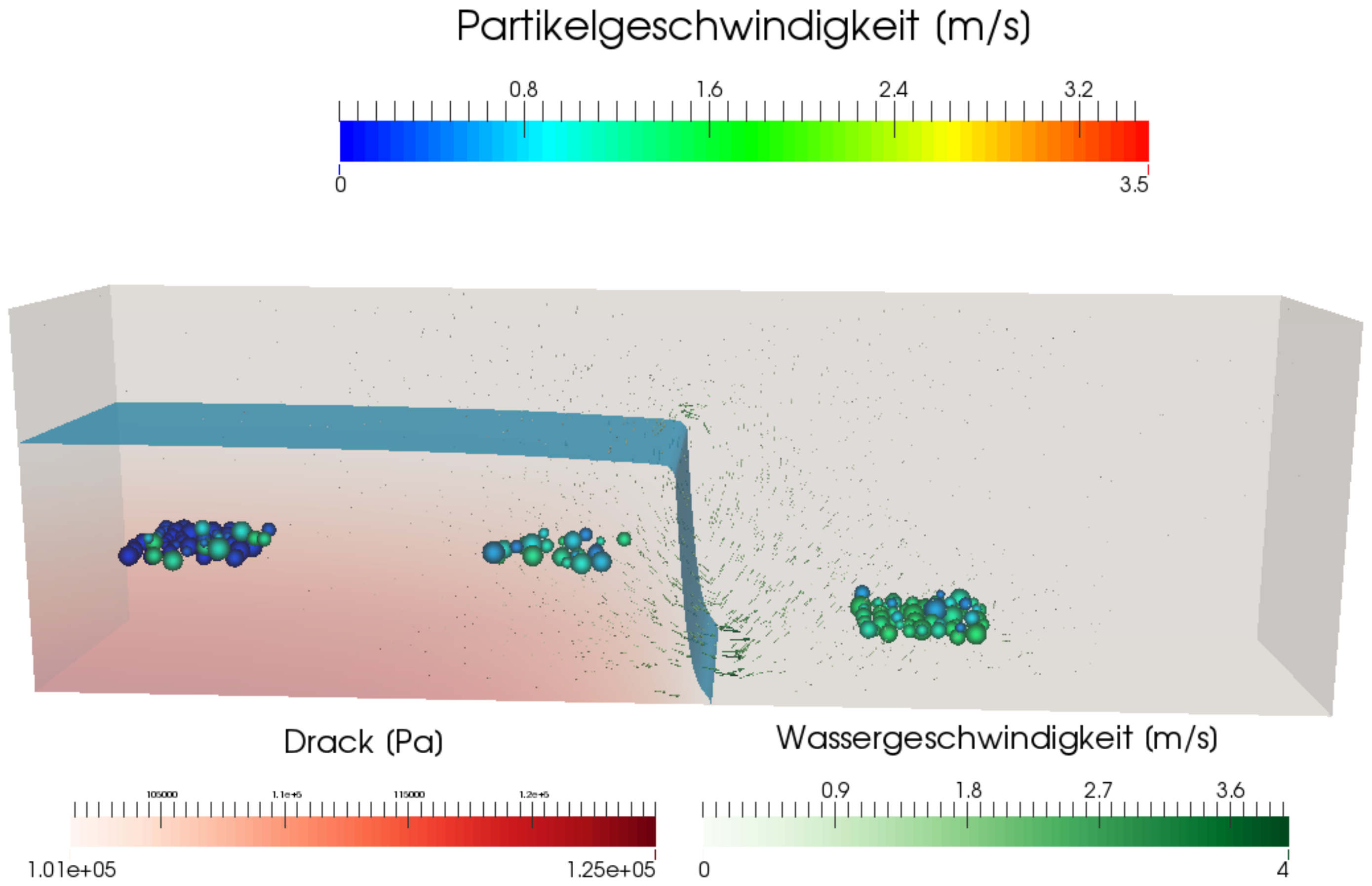


_Abb. 1: Ausgangskonfiguration mit drei verschiedenen Partikelagglomerationen, wobei die rechte Partikelfraktion leichter als Wasser ist und die Dichte der beiden verbleibenden Fraktionen größer als die von Wasser ist. Durch einen simulierten Dammbruch wird die hinter dem Damm aufgestaute Wassermenge augenblicklich freigesetzt.

Deshalb wird im vorliegenden Beitrag eine neue und innovative numerischer Ansatz vorgestellt, der den Transport von Treibgut bei Hochwasser aber auch bei Normalwasser beschreibt. Dazu werden die beiden numerischen Methoden beruhend auf einem diskreten und kontinuierlichem Ansatz gekoppelt. Letzterer beinhaltet die Euler Methoden, mit denen die Strömung des Wassers im Rahmen von bewährten Rechenmethoden der Computational Fluid Dynamik (CFD) bestimmt wird.

Treibgut wird diskret betrachtet, in dem es mit der Diskreten Element Methode (DEM) beschrieben wird. Damit kann sowohl jedes einzelne Element des Treibgutes berücksichtigt werden als auch seine Eigenschaften wie Größe, Form und Gewicht. Innerhalb dieses Ansatzes können die Kontaktkräfte zwischen den einzelnen Elementen des Treibgutes berechnet werden, mit denen sich Geschwindigkeit, Position und Orientierung des Treibgutes bestimmen lassen. Zusätzlich wird über eine

Kopplung zur fluiden Phase der Einfluss sowohl der Wassergeschwindigkeit als des Auftriebs mit berücksichtigt. Der Transport von Treibgut bei Hochwasser ist eine durch Schwerkraft dominierte Bewegung, wobei allerdings der Wasseranteil weit grösser ist als bei Muren. Murgänge sind eine Mischung aus Sand, Schlamm, Ton, Kies, Geröll, Wasser und anderen Substanzen, die sich unter dem Einfluss der Schwerkraft bewegen.

In der Regel kosten sowohl Hochwasser mit Treibgut und Muren zahlreiche Menschenleben und verursachen enorme Schäden, wobei die Zerstörungskraft von Muren meistens grösser als die von Überschwemmungen ist. Entscheidend für den Grad der Zerstörung von Muren ist die Wechselwirkung der Feststoffe untereinander und Wasser. Deshalb ist es von entscheidender Bedeutung die Wechselwirkung zwischen Wasser und den Feststoffen zu verstehen, um die Wirkung zu erfassen und aber auch die mechanische Festigkeit von Schutzmaßnahmen zu bestimmen.

Experimentelle Untersuchungen sind nur schwierig durchführbar, da die Installation von Messgeräten sehr schwierig ist, auch wegen ihrer mechanischen Festigkeit. Trotzdem sind experimentelle Messdaten verfügbar von Hu et al. (2011), Zhang (1993), Iverson (1997), Major (1996), und Iverson et al. (2010), die allerdings skaliert werden müssen, um auf reale Ereignisse übertragen werden zu können.

**Numerische Methode**

Der Transport von Treibgut wir über einen hybriden Ansatz beschrieben, für den diskrete mit kontinuierlichen Methoden gekoppelt werden. Zu diesem Zweck wird die Bewegung von Treibgut mit der Discrete Element Method (DEM) beschrieben, während die umgebende Fluidphase bestehend aus Wasser und Luft mit den klassischen Methoden der Computational Fluid Dynamics (CFD) als Zweiphasenströmung beschrieben wird wie bei Tryggvason et al. (2011). Mit dem diskreten Ansatz für feste Objekte im allgemeinen werden ihre Bewegungsbahnen im Sinne der Newtonschen Mechanik berechnet. Kräfte, die zwischen Wasser und Treibgut wechselwirken, beinhalten im wesentlichen Auftrieb, Widerstandskräfte, Kontaktkräfte zwischen dem Treibgut und Bauwerken.

**Ergebnisse**

Mit dem oben beschriebenen hybriden Ansatz wurde in einem ersten Schritt die Bewegung von kugelförmigen Treibgut berechnet, um den hybriden Ansatz an einfachen Geometrien zu verifizieren. Im weiteren Verlauf des Projektes werden reale Geometrien für Treibgut betrachtet, die über ein Oberflächengitter wie beispielsweise im STL-Format dargestellt werden. Dementsprechend wurde für erste Rechnungen 3 Partikelagglomerationen mit verschiedener Dichte wie in Abb. 1 dargestellt.

Dabei wurde dem rechten Agglomerat eine Dichte leichter als Wasser zugewiesen, so dass diese Partikel ähnlich dem Treibgut auf Wasser aufschwimmen und an der Wasseroberfläche transportiert werden. Die mittlere Partikelfraktion ist schwerer als Wasser und setzen sich als Sediment am Grund ab und werden entsprechend der Wechselwirkung mit der Grundwasserströmung transportiert. Die rechte Fraktion enthält Partikel die sowohl schwerer als auch leichter als Wasser sind, so dass ein Teil absinken wird während die verbleibenden Partikel auf der Wasseroberfläche aufschwimmen.

Um dem Wasser eine ähnlich hohe Dynamik wie bei Überschwemmungen zu geben, wurde eine Dammbruch simuliert, der augenblicklich die hinter dem Damm zurückgehaltene Wassermenge freisetzt (Abb. 1).

Die Bewegung des Wassers wird durch die Position der freien Oberfläche und die Vektoren der Wassergeschwindigkeit charakterisiert, wohingegen die Bewegung der Luft nur durch Geschwindigkeitsvektoren repräsentiert wird wie es in Abb. 2 gezeigt ist. Erwartungsgemäß ergeben sich an der Front des herabstürzenden Wassers die größten Geschwindigkeiten mit Werten bis zu 4 m/s. Die rechte und leichte Partikelfraktion wird von der Frontwelle komplett erfasst und erfährt dadurch eine starke Wechselwirkung mit der Strömung.

Zunächst werden die Partikel von der Strömung erfasst und auf Geschwindigkeiten bis zu 3.5 m/s beschleunigt. Dabei tritt eine starke Wechselwirkung der Partikel untereinander, hervorgerufen durch Kontaktkräfte, auf, die die Bewegung und damit die Trajektorien der Partikel bestimmt. Da die mittlere und linke Partikelfraktion teilweise schwerer als Wasser ist, sinken die Partikel zunächst unter Einfluss der Schwerkraft auf den Grund ab, währen die leichteren Partikel aufgrund des Auftriebs an die Wasseroberfläche aufsteigen. Im hinteren Bereich des Wassers treten zu diesem Zeitpunkt noch vernachlässigbare Wassergeschwindigkeiten auf, so dass die Partikel hauptsächlich unter dem Einfluss von Schwerkraft und Auftrieb stehen und die horizontalen Geschwindigkeitskomponenten vernachlässigbar sind.

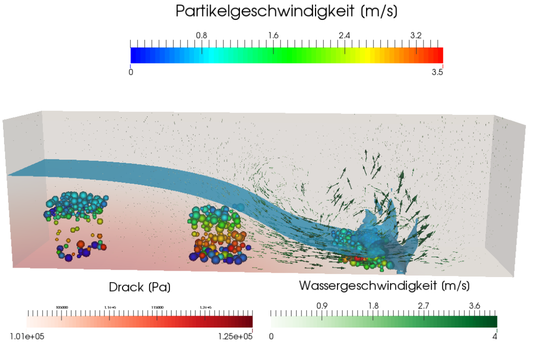


_Abb. 3: Darstellung der Strömungsverhältnisse für Wasser und Luft zusammen mit den Partikelgeschwindigkeiten zum Zeitpunkt 1.2 s. Beim Auftreffen der Frontwelle auf die Wand werden sowohl die Strömung des Wassers nach oben abgelenkt als auch die Partikel stark beschleunigt, sodass sie teilweise der Wassergeschwindigkeit folgen. Die hinteren Partikelfraktionen sinken weiterhin unter dem Einfluss der Schwerkraft auf den Grund.

Die folgende Abb. 3 zeigt den Aufprall der Frontwelle auf die gegenüberliegende Wand, wobei eine starke Wechselwirkung zwischen Wand, Wasser und Partikeln auftritt, die als 4-Weg-Kopplung folgende Wechselwirkungen enthält:

1. Partikel-Partikel
2. Partikel-Wand
3. Partikel-Wasser
4. Wasser-Partikel (Wand)

und sowohl die Strömung des Wassers als auch die Bewegung der Partikel beeinflusst. Für die hinteren Partikelfraktionen ist immer noch die Schwerkraft die dominierende Kraft, so dass sie weiterhin auf den Grund sinken. Nur die mittlere Partikelfraktion zeigt bereits eine Wechselwirkung mit dem Wasser, so dass bereitsauf den Grund abgesunkene Partikel teilweise mit der Strömung mit bewegt werden und Sedimenttransport repräsentiert.

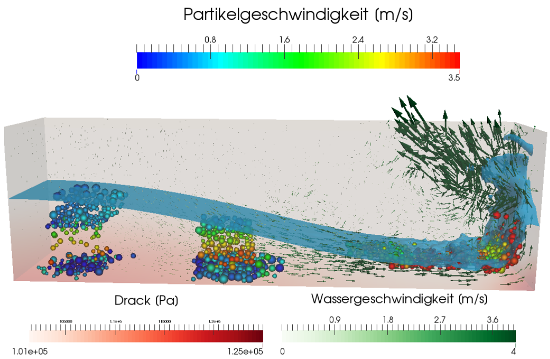


_Abb. 2: Darstellung der Strömungsverhältnisse für Wasser und Luft zusammen mit den Partikelgeschwindigkeiten zum Zeitpunkt 0.65 s. Während die vordere Partikelfraktion durch das herabstürzende Wasser auf Geschwindigkeiten bis zu 3.5 m/s beschleunigt werden, sinken die hinteren Partikelfraktionen unter dem Einfluss der Schwerkraft und vernachlässigbarer Wassergeschwindigkeiten auf den Grund.

Die beiden folgenden Abb. 4 und 5 zeigen das Rückschwappen der Welle, hervorgerufen durch den Aufprall auf die Wand. Dadurch tritt ein starker Rückströmungseffekt auf, dem die Partikel wegen ihrer Trägheit mit einer Zeitverzögerung folgen. Zusätzlich ist die Wasseroberfläche nach der Reflektion an der Wand stark deformiert, wodurch einige Oberflächenpartikel mitgerissen werden und der turbulenten Strömung folgen.

Die rechte Partikelfraktion hat sich bereits zu diesem Zeitpunkt entmischt, so dass schwere Partikel auf den Grund abgesunken sind und die Leichteren auf der Wasseroberfläche aufschwimmen. Da bereits auch schon im hinteren Teil merkliche Wassergeschwindigkeiten auftreten, werden die leichteren Partikel an der Oberfläche bereits mit gerissen.

Die mittlere Partikelfraktion, allesamt bestehend aus schwereren Partikeln, sind auf den Grund abgesunken und werden ähnlich einem Sediment mit der Grundströmung bewegt.

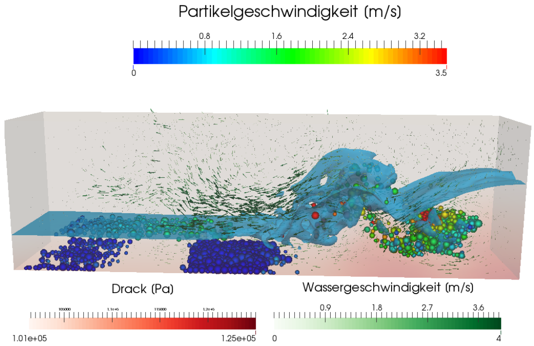


_Abb. 4: Darstellung der Strömungsverhältnisse für Wasser und Luft zusammen mit den Partikelgeschwindigkeiten zum Zeitpunkt 3.0 s. Durch das Zurückschwappen der Frontwelle wird die Wasseroberfläche stark deformiert und reißt einige Partikel mit sich. Schwere Partikel als Sediment abgesetzt werden durch die Grundströmung nur mäßig bewegt, während im hinteren Bereich aufschwimmende Partikel durch die turbulente Strömung mitgerissen werden.

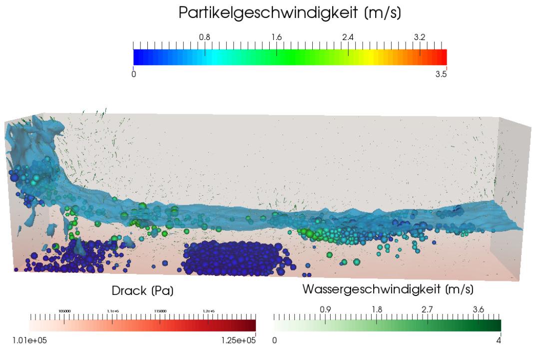


_Abb. 5: Darstellung der Strömungsverhältnisse für Wasser und Luft zusammen mit den Partikelgeschwindigkeiten zum Zeitpunkt 5.2 s. Durch den Aufprall der Welle an der rechten Wand wird die Wasseroberfläche wiederum stark deformiert und aufschwimmende Partikel werden mitgerissen. Auf den Grund abgesunkene Partikel werden nur mäßig bewegt.

## Zusammenfassung

In diesem Beitrag wurde eine Methode vorgestellt, mit der der Transport von Treibgut auf Wasseroberflächen beschrieben werden kann. Dazu wurde eine hybride Methode entwickelt, die die kontinuierlichen Methoden der klassischen Computational Fluid Dynamics (CFD) mit der Discrete Element Method (DEM) koppelt. Dabei wird das Treibgut bestehend aus einzelnen Objekten beschrieben, auf die Wasser- Kontakt-, Auftriebs- und Schwerkräfte wirken. Damit kann die Bewegung und die Trajektorien der Treibgutobjekte im Rahmen eines Lagrange-Ansatzes bestimmt werden. Die Strömung des Wassers wird als Zweiphasenströmung mit frier Oberfläche repräsentiert. Mit der numerischen Methode wurden erste Verifizierungsrechnungen durchgeführt, die sowohl den Transport von Partikeln an der Wasseroberfläche als die Bewegung von schwereren Partikeln auf dem Grund beschreiben.

### Literatur

Hu, K., Wei, F., and Li, Y. (2011): Real-time measurement and preliminary anal- ysis of debris-flow impact force at Jiangjia Ravine, China., Earth Surface Processes and Landforms, 36(9), 12681278. doi:10.1002/esp.2155, 2011.

Iverson, R. M. (1997): The physics of debris flows., Reviews of Geophysics, 35(97), 245. doi:10.1029/97RG00426, 1997.

Iverson, R. M., Logan, M., LaHusen, R. G., and Berti, M. (2010): The perfect debris flow? Aggregated results from 28 large-scale experiments. Journal of Geophysical Research, 115(F3), F03005. doi:10.1029/2009JF001514, 2010.

Major, J. J. (1996): Experimental studies of deposition by debris flows: process, characteristics of deposits, and effects of pore-fluid pressure. PhD, Washington, 1996.

Major, J. J. and Iverson, R. M. (1999): Debris-flow deposition: Effects of pore-uid pressure and friction concentrated at flow margins. Bulletin of the Geological Society of America, 111(10), 14241434. doi:10.1130/0016- 7606(1999)111<1424:DFDEOP>2.3.CO 1999.

Tryggvason, G., Scardovelli, R., Zaleski, S. (2011): Direct numerical simulations of gas-liquid multiphase flows, Cambridge University Press, 2011.

Zhang S. A. (1993): Comprehensive approach to the observation and prevention of debris flows in China., Natural Hazards 7:123, 1993.


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**The following article describes a part of the doctoral thesis realised by the doctoral student Shahriar Agaajani and supervised by Danièle Waldmann-Diederich, head of the Laboratory of Solid Structures at the University of Luxembourg. The research work of the thesis has been internationally awarded from the London-based International Masonry Society for the best doctoral thesis of 2015. By end of the year 2016 the Journal Masonry International will publish the article in its current form.**

# NUMERICAL ANALYSIS FOR THE DETERMINATION OF STRESS PERCOLATION IN DRY-STACKED WALL SYSTEMS_

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**Abstract**

This paper comprises a portion of a PhD study concluding on the potential use of a new mortarless and modular masonry system by taking into consideration the outcome of a multidisciplinary study including aspects of experimental, numerical and analytical investigations in relation to a practical and economical development of modular load-bearing dry-stacked masonry systems. Different forms of interlocking masonry elements have been modelled and optimised thermo-mechanically. Full-scale masonry walls were assembled and tested experimentally under compressive, flexural, shear, cyclic and long term loads. The overall structural behaviour was compared to conventional masonry systems such as hollow and shuttering blocks. The investigations showed overall relative high structural performances for the developed dry-stacked elements.

The effect of dry joint interfaces was extensively investigated experimentally and numerically under FE analysis. Based on the experimental observations, a numeric-analytical failure mechanism of the dry-stacked masonry structure is anticipated under axial and flexural loading. The structural investigations and engineering processes are completed by the development of a package of dry-stacked units consisting of interlocking modular masonries and an accompanying array of various other precast parts. This confirmed the practical issues and solutions towards the exploitation of the developed dry-stacked elements for the construction of ready-to-build, modular and load-bearing walls.

The portion of work presented herein proposes a new numerical technique for the determination of stress-percolation in dry stacked load-bearing structures. The model is developed in three steps under a numerical computing environment. First, based on geometrical properties of the dry-stacked elements and with a linear-elastic material behaviour, the load percolation and intensity in dry-stacked masonry walls is determined. In a second step, a phenomenon known as a plastic accommodation which accompanies the redistribution of the stress percolations, is incorporated in the model. This enables the understanding of the evolution of the stress percolations in the post-elastic phase, which is crucial for the determination of the load capacity and stability of the structure in function of an increased external load. This paper also supports the better understanding of early fissuring in dry-stacked masonry structures which has an important influence on the overall stability of the structure. Finally, in a third step, the improvement of dry-stacked structures is pursued by further analysis of the results obtained through the algorithm.

This paper represents a new tool for investigating the localized and randomly defined internal stress distribution induced by external compression forces on dry-stacked structures. Furthermore, the algorithm illustrates that experimental investigations on dry-stacked systems may only give real indications on the load capacity of the structure, when the number of joint interfaces and height to length ratio of the block is respected and that results of experimental investigations on reduced prism specimens may not be extrapolated to full sized walls as they may over-evaluate the effective loaded masonry sections and therefore the overall load capacity. Keywords: masonry, dry-stacked, load percolation and intensity, strength, mortarless contact, modular block, load-bearing wall.

**Notations:**

| | |
|---|---|
| h | block or wall height |
| μ | mean value |
| σ | standard deviation |
| [H] | matrix H |
| $h_{block}$ | block height |
| randperm(p) | returns a random value of the integers 1 to p |
| $[B]_{full}$ and $[B]_{half}$ | individual full or half blocks |
| $N_{ij}$ | node i,j |
| [W] | matrix W |
| α | alpha |
| L | length of wall |
| $A_{eff,i}$ | effective loaded area Aeff,i at a given row i |
| $k_i$ | reduction factor in row i |
| $A_{nom,i}$ | nominal contact area in row i |
| n | number of cases |
| $k_{min}$ | minimal reduction factor |
| $k_{min,env.}$ | minimal envelope |
| $\Delta h_{wall}$ | height difference in structures |

**Introduction**

The understanding of structural behaviour of dry-stacked masonry systems implies defining load percolation, effective contact area at joint interface and determining the resulting stresses in the critical wall sections.

1_ Founded in 1986, The International Masonry Society has a membership from throughout the world and an international reputation in the field of masonry literature, the dissemination of research and current thinking. There are currently members in 31 countries, including those from Africa, Asia, Europe, both North and South America, Canada, Australia and New Zealand. The objectives of the International Masonry Society are to promote discussion and advancement of the science and practice of masonry as allied to its constituent materials, and to all aspects of the design and use of masonry and the construction process.

On the other hand, the production tolerances of dry-stacked masonry elements imply dimensional inaccuracies which have a substantial impact on the load-capacity and failure mode of the constructed walls. The effect of individual block height on stress percolation is investigated by developing a new technique in a numerical computing environment. This numerical investigation gives the relationship between the effective contact areas in a dry-stacked masonry wall in function of the production tolerances and demonstrates that the contact area at the joint interface is under certain circumstances significantly lower than previously estimated. As a consequence, the better perception of the load percolation and intensity enables the development of post-elastic failure theories and masonry-shape improvement.

**Load percolation in dry-stacked structures**

As the mortared layers between the consecutive rows in a dry-stacked system are missing, the individual blocks must have exactly the same height for a uniform load distribution and transfer between the elements (Figure 1).

_Fig. 1: Dry-stacked masonry (Agaajani et al., 2015)

As a matter of fact, this ideal case is in reality not possible because of the production tolerances and dimensional inaccuracies, which induce a block-height distribution as pointed out in Figure 2. These geometrical imperfections induce localized and almost unique internal stress distributions induced by external loads within the dry-stacked masonry wall.

Essentially the height differences between adjacent masonry elements, and marginally the variation of width of successive masonry rows for the block design shown in Figure 1, have an impact on the load-capacity and failure mode of the constructed walls.

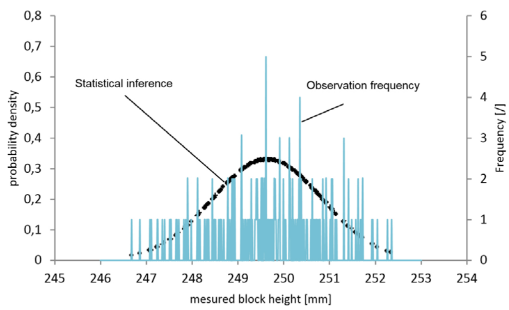


_Fig. 2: Normal distribution (black) and frequency (blue) of masonry height distribution of manufactured elements (Agaajani et al., 2015)

Past observations on load-bearing and dry-stacked masonry walls tried to analyse on how a dry-stacked masonry system respond to external loads. Although many experimental investigations have been undertaken in order to better understand the behaviour of these systems (Oh K., 1994) (Marzahn & König, 2002) (Drysdale, 2005) the load percolation within the walls have not been fully explained.

Transmission photoelasticity on stretcher-bond scale models have been experimented, reproducing the load percolation of a locally applied vertical compressive force in photoelastic materials such as Plexiglas® (Bigoni, 2009). The results reveal localized, curvilinear stress percolations which do not diffuse as they would in a reinforced concrete system, but tend to percolate along high stiffness lines. Yet, a post-elastic approach such as cracking and its resulting consequences is not suggested.

This topic remains crucial for the understanding of stress distribution and intensity and is deepened within this research work by the development of a specific algorithm. The developed algorithm is based, in a first step, on a linear approach and thus no cracking of the elements is considered. In a second step, a post-elastic phase is considered by a deeper analysis of the sections with the highest stress concentrations.

**Numerical setup and computing**

By measuring the individual height of randomly selected blocks with a precision of 0.01 mm, a frequency distribution may be obtained in function of the height of the blocks (Figure 2), which may serve as an example to illustrate the geometrical imperfections. Although the distribution is slightly left-tailed (Table 1), the normal bell curve may be applied, and on account for its simplicity, we may use it as a first approximation:

$$f(h,\mu,\sigma)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(h-\mu)^2}{2\sigma^2}} \qquad \text{Eq. 1}$$

Where the parameter h is the measured block height, μ is the mean value and σ the standard deviation of the distribution.

**Table 1**

Statistical parameters (in mm) due to geometric imperfections in block production.

| Nominal height | Mean value | Median value | Standard deviation |
|---|---|---|---|
| 250 | 249.64 | 249.62 | 1.20 |

Blocks with different heights (Equation 2) are chosen randomly (Equation 3) and stacked one by one until the desired height and length of the structure [W] is achieved (Equation 6 and Figure 4).

$$[H]=\begin{bmatrix} h_p=\mu-3\sigma \\ \vdots \\ h_i=\mu \\ \vdots \\ h_1=\mu+3\sigma \end{bmatrix} \qquad \text{Eq. 2}$$

The matrix *[H]* contains the empirical height measurements less than three standard deviations σ away from the mean value μ. For the discrete probability density function (Equation 1) this accounts for 99.7% of the set. The randomly dry-stacked blocks are chosen by:

$$h_{block}=[H(randperm(p))] \qquad \text{Eq. 3}$$

Where $h_{block}$ is the block height and [H] is a column matrix; randperm returns a random value of the integers 1 to p, where p is the size of the matrix *[H]*.

Individual full blocks [B]*full* are modelled by 8 nodes (Equation 4), whereas the half blocks [B]*half* are modelled by only 4 nodes (Equation 5). The height difference between the upper and lower nodes is defined by Equation 3.

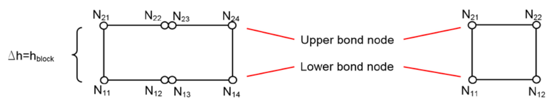


_Fig. 3: Definition of nodes of full and half masonry elements

$$[B]_{full}=\begin{bmatrix} N_{21} & N_{22} & N_{23} & N_{24} \\ N_{11} & N_{12} & N_{13} & N_{14} \end{bmatrix} \qquad \text{Eq. 3}$$

$$[B]_{half}=\begin{bmatrix} N_{21} & N_{22} \\ N_{11} & N_{12} \end{bmatrix} \qquad \text{Eq. 4}$$

The "dry-stacking" of the masonry elements is implemented by incorporating the individual full and half masonry elements [B]i,j in a global matrix [W], which contains all the elements. The matrix [W], or wall, is constructed by placing the first row of elements on a perfectly horizontal line (corresponding to a mortared ground layer), and by placing the following rows in stretcher bond, for example. The ends of the structure are held laterally, which prohibits the rotation of the individual blocks. The load is applied uniformly on the upper and lower end (Figure 4), while the dead load weight is omitted.

$$[W] = \begin{bmatrix} [B]_{1,j} & \cdots & [B]_{i,j} \\ \vdots & \ddots & \vdots \\ [B]_{1,1} & \cdots & [B]_{i,1} \end{bmatrix} \quad \text{Eq. 6}$$

### Load percolation and intensity

Figure 4 shows the example of a two-row wall structure of 2.5m length made of blocks with height variations corresponding to the frequency distribution of Table 1. The height difference between adjacent blocks is arbitrarily magnified for visualisation purposes (factor of 10). The load transmission from one row to another depends on the contact interfaces between the elements. The local rotation of the elements is not permitted and the horizontal gap between the elements is supposed to prohibit horizontal load transfer. Thus, it is assumed that forces percolate only vertically through the masonry rows.

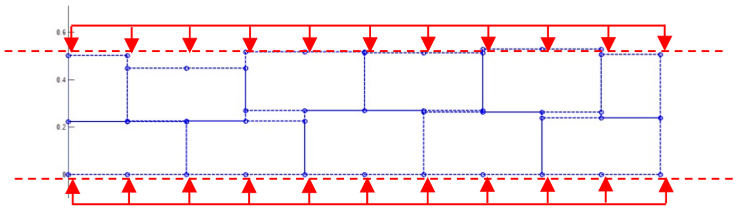
_Fig. 4: Randomly chosen blocks with different heights and dry-stacked with stretcher bond

The gap between two adjacent blocks causes the disruption of the uniform load percolation which can be transmitted through the contact interface. As a consequence, the load is channelled through neighbouring contact interfaces, resulting in higher stress concentrations.

In Figure 5 two 2.5 x 2.5 meter wall structures are mounted with blocks of exactly the same height, except one. In this first analysis, the block located in the middle of the lowest row is slightly higher than its neighbours. In the second case, the block with the higher height is located in the middle of the structure.

In both cases, the block with the largest height tends to channel the load transmission by an angle α (angle taken from the vertical line of the load) above its location, which reduces the effective loaded area and induces high concentrations of stresses. It redistributes the load by the angle α, which may be given by:

$$\alpha = \tan^{-1}\left(\frac{\frac{L_{bloc}}{2}}{h_{bloc}}\right)$$

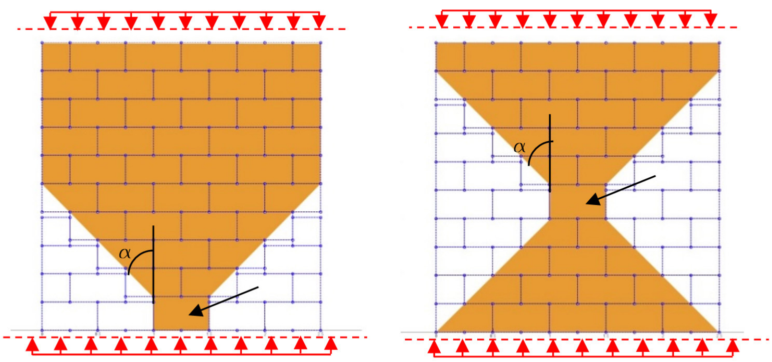

_Fig. 5: Visualisation of load-transmission in a dry-stacked wall structure using the above mentioned algorithm

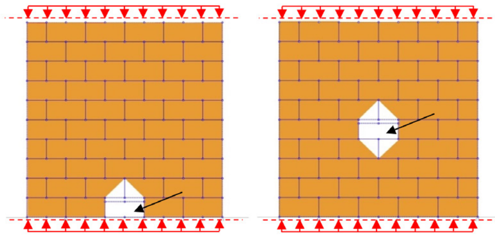
_Fig. 6: Influence of reduced block height on load transmission in dry-stacked wall systems

### Load percolation in dry-stacked structures

Numerical simulations with randomly selected height values for every individual block show characteristic patterns of load distribution and transfer between the block elements in the structure. While the load is uniformly applied on the extremities of the wall, the effective area acting in the load transmission varies from row to row and decreases significantly to a minimum at the first basis rows (Figure 7 and 8).

There are as many load percolations as stacking possibilities of randomly chosen blocks. Thus, we may state that the load percolation between each row is determined by a probabilistic state which is a function of the geometric properties of the used block population. Generally, the load distribution varies throughout the height of the structure and is percolated through tree-like ramifications to the base, where only a small fraction of the total wall section is exploited. Noted that the obtained load percolations do not take into consideration stress intensities.

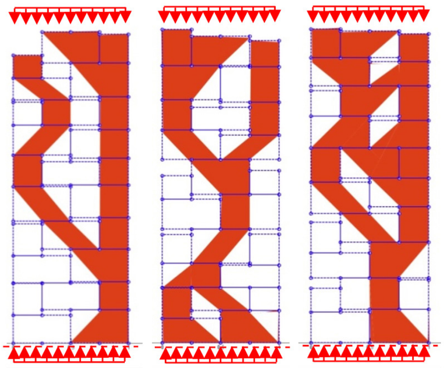
_Fig. 7: Load percolation in wall structures of 2.50m height and L = 1.00m length

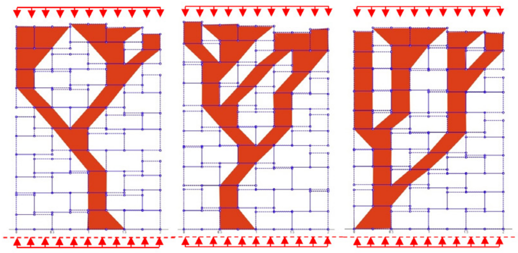
_Fig. 8: Load percolation in wall structures of 2.50m height and L = 2.00m length

The above mentioned observations make analogy to numerical analysis and research of granular structures (Radjai, 1996) (Breton & Jussien), where the load transmissions through the more rigid structure is preferred and where curvilinear compressive stress lines occur (Figure 9).

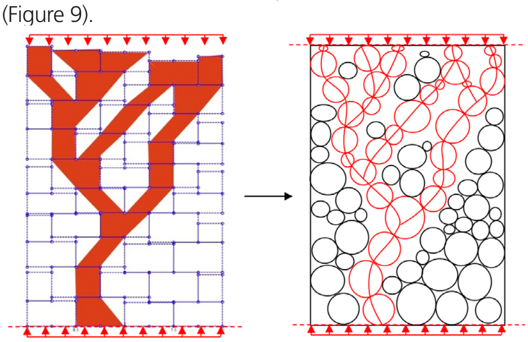
_Fig. 9: Analogy to granular structures

Linear Finite Element analysis' have been modelled (Figure 10) in order to validate the stress percolation in dry-stacked structures obtained through the developed algorithm. The results show virtually identical tree-like stress percolations, although the FEA may slightly better represent the stress diffusion in the different rows of the structure. However, the main added value through the FEA, which are also time expensive (pre-and and post-processing included), is the visualisation and determination of the developed stress intensity in the critical sections.
Figure 10 shows that for an external vertical load of 1 MN/m² applied uniformly on each face-shell of the dry-stacked wall (Figure 1), the principal stress in the critical section of the structure may be 30 times higher than the least compressed sections (Agaajani et al., 2015). This additional numerical observation gives an inside in where initial cracking may occur and how the dry-stacked structures evolve in the post-elastic phase.

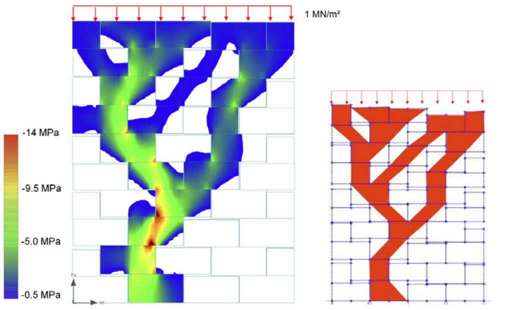

_Fig. 10: Stress percolation and intensity seen in a dry-stacked structure through FE Analysis (l.), compared to stress percolation obtained through the developed algorithm (r.)

In Figure 11, where the length of the structure is a multiple of its height L > h, characteristic load distribution patterns are distinguished in comparison to the above mentioned structures (where h > L).
The global load transmission is improved, as the lower sections in the wall structure are better solicited through additional curvilinear compressive stress curves, or load percolations. Half-blocks are, if under compression, always entirely under compression, while full blocks are often only partially under compression. This observation elucidates why, in the running bond system, most of the full blocks and none of the half blocks were cracked on the load-bearing face shells during experimental loadings (Agaajani et al., 2015).

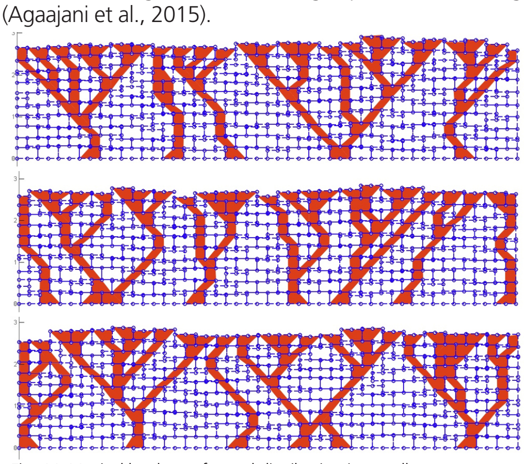
_Fig. 11: Vertical load transfer and distribution in a wall structure of ~2.50m height and L = 12.00m length, with amplified standard deviation of 0.02m in height of randomly selected blocs (Agaajani et al., 2015)

**Characteristic load intensities based on linear elastic behaviour**

The effective loaded area Aeff,i at a given row i in the masonry structure (Figure 12) is given by the relation:

$$A_{eff,i} = k_i \cdot A_{nom,i} \quad \text{Eq. 8}$$

where $k_i$ is a reduction factor of the loaded area at the contact interface between the rows i and i+1 due to the height differences between adjacent masonry elements, and $A_{nom,i}$ the nominal loaded area between the rows i and i+1.

The reduction factor $k_i$ may be estimated by calculations based on statistical dispersions and geometric properties of individual block elements:

$$k_i = \frac{\sum_{c=1}^{n} \frac{A_{eff,i}}{A_{nom,i}}}{n} \quad \text{Eq. 9}$$

Where n is the total number of analysed cases c in order to obtain an average value based on statistical dispersions and load percolations, for a given structure of height h and length l.

The existence of a minimal effective contact area $A_{eff,min,wall}$ is determined analytically in every dry-stacked structure and is defined by the geometrical properties of the individual block elements and of the entire structure:

$$k_{min} = \frac{1}{2} \cdot max\left(\frac{h_{block}}{h}; \frac{L_{block}}{L}\right) \quad \text{Eq. 10}$$

Where, $L_{block}$ and $h_{block}$ are the length, respectively the height of a single block, L and h are the length, respectively height of the entire dry-stacked structure.

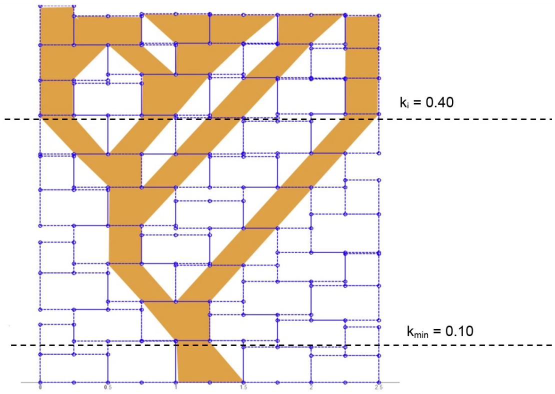

_Fig. 12: Example of effective area calculation for the determination of the stress state in the dry-stacked masonry

As a result, locally concentrated forces cause premature cracking in the dry-stacked masonry elements and reduce the overall elastic behaviour and load-bearing capacities of the wall.

In Figure 13 the statistically determined evolution of the reduction coefficient of the loaded area, for a 2.50m high structure and varying lengths is shown. This reduction coefficient retraces for each row the relation between the effective loaded area due to imperfections and the theoretic global total area depending on different wall lengths (from L=0.25m to L=12m). The minimum envelope, the heavy black line (Equation 11), representing an endless length of the wall shows a drastic reduction of the loaded area in the lower part of the masonry structure (reduction of 80-90% at the four lowest courses of the masonry). The test results of Jaafar et al. (2006), where large differences in normal displacements at joint interfaces were measured at different locations, show during experiments the same behaviour: the crushing at joint interface was higher in the lower rows than the upper ones.

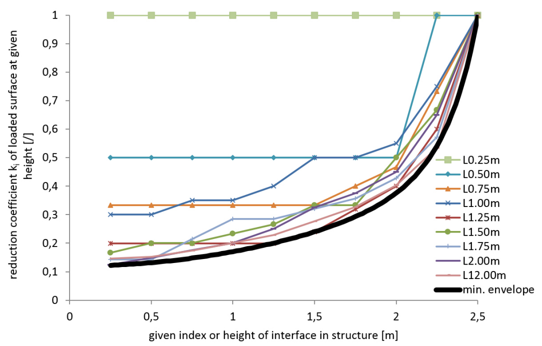

_Fig. 13: Evolution of the reduction coefficient of loaded surface area

The statistically determined minimum reduction factor kmin_env is numerically approached by non-linear curve fitting and represented by the Equation 11:

$$k_{min\_env.} = 0.12 + 0.05h^2 + 0.0011e^{h^2} \quad for\ h \in [0.25, 2.50m] \quad \text{Eq. 11}$$

The column-wall dry-stacked with half blocks (L=0.25m) does not have any adjacent neighbouring blocks with different heights, and keeps therefore a reduction coefficient equal to 1 all over the height of the wall. For running-bonded structures of L = 0.50m and more, the distribution frequency (Figure 2) plays an important role and the reduction coefficient is drastically decreased in function of a growing length of the wall and position of the contact interface in the structure (Figure 13). For any h/L ratio, the poorest contact interface between the dry-stacked rows is reached on the interfaces of the lowest rows. This is a very important observation as it may demonstrate where initial cracking may occur. Furthermore, Figure 13 is obtained for a fixed height of 2.50m and variable length of dry-stacked system. Additional simulations for alternative wall heights shall give more details about the reduction coefficient $k_i$.

**Deviation of global height in dry-stacked structures**

The random and non-linear difference in wall height between a dry-stacked structure, where all block elements have the same height, and a structure composed of blocks with a given standard deviation of their height corresponding to the actual production series (Table 1 and Equation 1), is analytically given by the relation (12):

$$\Delta h_{wall} = 0.6h^2 + 2.9h + 1.7 \quad [mm]$$
$$for\ h \in [0.25, 2.50m]$$

In the particular case (standard deviation of 1.2 mm), a desired structure of 2.50 m height would be statistically ~13 mm higher (~0.5%).

**Post-elastic phases in dry-stacked masonry systems**

According to the previous observations, the understanding of stress distribution within dry-stacked masonry walls is found to be complex. The load distribution between the dry-stacked rows is being dominated by randomness and tree-like geometrical schemes with even analogy to granular medium (Figure 9). Stress percolation is highly localized in the lower rows, highlighting stress streams in contrast to unloaded areas in the dry-stacked masonry walls. The evolution of these structures in the post-elastic phase with the associated stress and crack development are crucial for the determination of the load capacity and stability of these structures.

The analysis of block height distribution may enable the understanding of load distribution and intensity of load transfer at contact interfaces of dry-stacked masonry structures. According to experiments carried out at the University of Luxembourg (Agaajani et al., 2015), a 1.0m large and 2.5m high dry-stacked wall is modelled in stretcher-bond (Figure 13) and a uniform load is applied at the top of the structure. It is again supposed that the lateral edges of the structure are pinned, which prohibits the rotation of the individual blocks. In the analysis the load is applied uniformly at the top and bottom of the structure while the dead load weight is neglected.

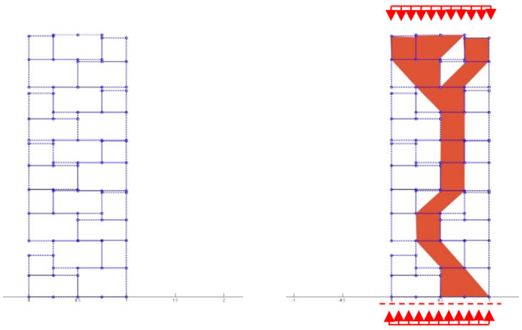

_Fig. 14: Numerical modelling of a 1.0 x 2.5m dry-stacked wall (height differences between adjacent elements exaggerated for visualisation purposes)

An expected tree-like stress distribution pattern is observed, as described in the previous sections. In accordance to the reduction of the loaded surface area in function of the position of the joint interface in the dry-stacked wall structure (Figure 15), the possible location of the critical wall section is found to be in the second row. The applied vertical load is then gradually increased, in order to initiate the damage or cracking of the critical section (Figure 15, left side). Due to the cracking of the critical element in the critical section, the concerned block is split in two parts, inducing a redistribution of stress percolation in the dry-stacked system which is illustrated in the right side of Figure 15.

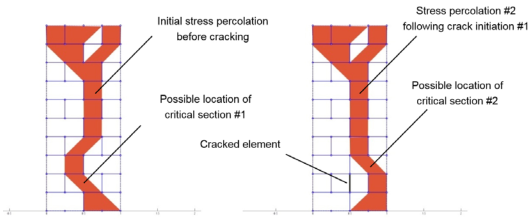


_Fig. 15: Comparison between initial stress distribution (left) and new stress distribution after cracking of the critical section #1 (right)

By further increasing the intensity of the applied vertical force, the next possible critical section is subjected to damage (Figure 15, right), and again, a new load and stress distribution is initiated as a result of this rearrangement of dry-stacked blocks in the dry-stacked wall (Figure 16, left). The rearrangement of the blocks and their involving stress redistribution is pursued with the increase of the applied load (Figure 16, right).

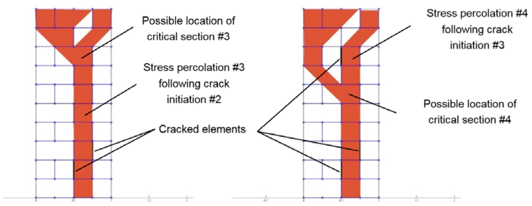


_Fig. 16: Comparison between initial stress distribution (left) and new stress distribution after cracking of the critical section #3 (right)

In contrast to traditional masonry wall constructions, where damage initiation only appears close to the ultimate load and is thus a sign of reaching the load bearing capacity, the dry-stacked systems enter, due to cracking, rather a state of a more homogenous stress distribution with enhanced load percolations due to increased effective contact areas at joint interfaces (Figure 17, left). The stability of the damaged dry-stacked wall is also enhanced compared to the un-cracked situation, in spite of the cracked block elements, as the stress streams are more uniformly distributed and unloaded areas are diminished. This phenomenon is known as a plastic accommodation which accompanies the redistribution of the stress percolations.

If the load is continuously increased, without consideration to the slenderness of the wall, all the full elements may be divided in two half blocks, transforming the stretcher-bond system in a stack-bond system where the masonry elements are aligned vertically. The wall would be transformed into individual pillars (Figure 16, right), implying the highest rate of effective contact area between adjacent rows in the dry-stacked system. Due to a possible lateral mechanical interlocking of the adjacent masonry elements, the different pillars may not fully be independent.

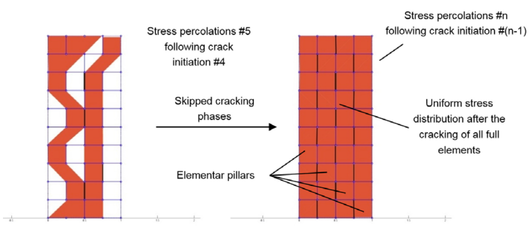


_Fig. 17: Comparison between stress distribution #5 (left) and final stress distribution #n after the cracking of all full block elements (right)

The splitting of the full blocks due to cracking, starting at the lower rows of the wall with an increasing vertical loading has systematically been observed during experimental investigations on stretcher-bonded, dry-stacked masonry walls (Figure 18) (Agaajani Shahriar et al., 2015). Indeed, the mentioned cracking of the blocks appeared long before the ultimate load has been reached. This proves the explained reorganisation of the stress distribution and reduction of stress intensity which takes place during the loading of the dry-stacked wall.

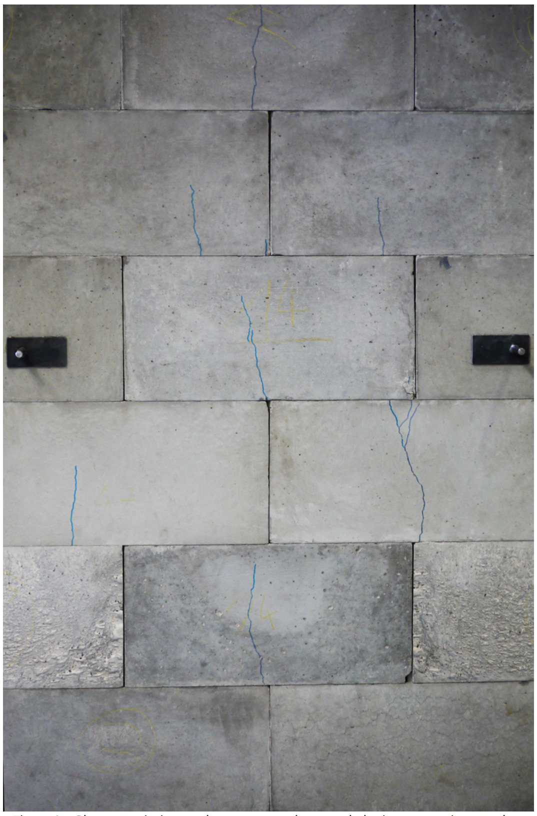

_Fig. 18: Characteristic crack patterns observed during experimental investigations involving vertical loadings and bending moments on stretcher-bonded and dry-stacked masonry structures

## Improvement of the load carrying behaviour

Repeating the same procedures and analysis with an increased block height of 0.50m, the load distribution through the dry-stacked masonry structure is modified and improved. Comparing Figures 8/11 and Figures 19 and 20, we notice that with the overall increased height of the elements, the load ramification intensity through the structure is enhanced and as a consequence, the load distribution is improved, involving a reduction of stress intensity at a given height in the structure.

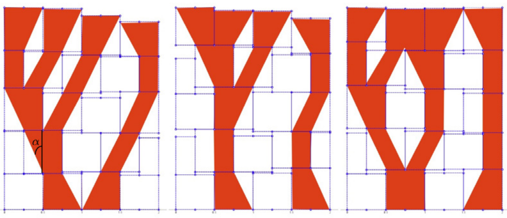

_Fig. 19: Load distribution in 2.00m long and 2.50m height structures

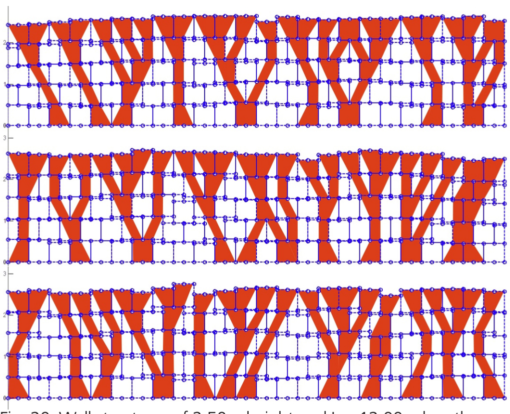

_Fig. 20: Wall structures of 2.50m height and L = 12.00m length

The maximum angle α of load transmission from one row to another is given by Equation (7) and is plotted in function of the ratio of the block height to block length in Figure 21. We notice that for a more uniform load transmission it is necessary to reduce the angle α of load transmission in order to get more curvilinear stress lines, or an increased number of tree-like ramifications, in a given structure. To reduce the angle of load transmission which means to reduce the inclination of the stress lines towards the vertical, the ratio of the height to the length of the blocks must be increased for a given block length.

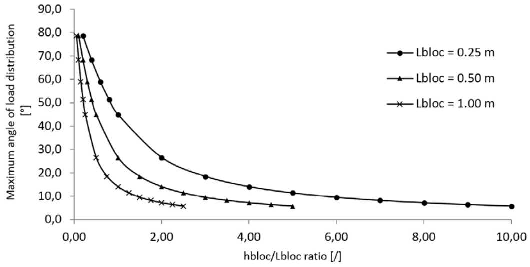


_Fig. 21: Maximum angle α of load transmission in function of h/L ratio of the masonry elements

An increased block height (0.50m instead of 0.25m) for a given block length of 0.50m enhances the reduction factor $k_i$ significantly which can be seen in Figure 22 and 23. As the number of intermediate joint interfaces is decreased from 9 to 4, there are less "disconnected contact layers", and thus the load transmission is enhanced. We notice that the effective contact area at the lowest joint interface is increased by about 100%.

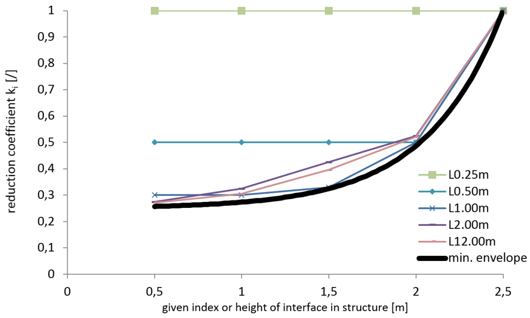


_Fig. 22: Reduction coefficient and minimum envelope of loaded area at a given index or height in dry-stacked structure of 2.50m height and for different lengths (n=5)

In comparison to equation (11), the reduction coefficient $k_i$ at a given joint interface i or height h in the improved structure (h/L = 1.0) is given by the approximate curve-fitted relation (12) and is plotted in Figure 23:

$$k_{i,min\_envelope} = 0.25 + 0.0024 \cdot 10^{h} \quad \text{Eq. 12}$$

$$for\ h \in [0.50, 2.50m]$$

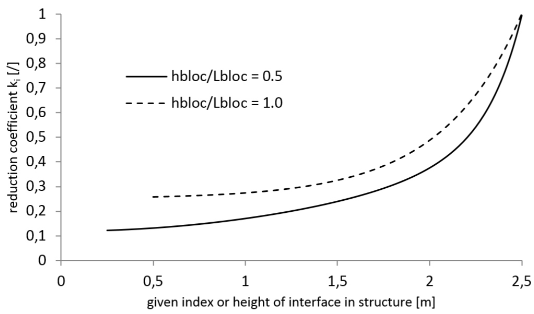


_Fig. 23: Comparison of reduction coefficient $k_i$ for different h/L ratios of block elements

We may therefore pretend that the global structural behaviour of a dry-stacked wall is significantly improved when elementary blocks have a height-to-length ratio of 1.0. The ratio of 1.0 may be a best practice as further restrictions such as block weight and manoeuvrability play also a significant role.

## Conclusions

With this work, a contribution in the field of dry-stacked masonry blocks in the domain of load percolation in dry-stacked structures and post-elastic failure theories is given.
The definition of the average contact area at joint interface between dry-stacked masonry elements in stretcher bond

is highly complex. The effective area acting in the load transmission varies from row to row and decreases significantly to a minimum at the lowest rows. This first reduction coefficient, due to the height variation in block production is dependent of the block dimensions, and improves when the height to length ratio of the elements is increased.

This observation is crucial for the understanding of stress and crack development in the dry stacked masonry structures. Under the condition that all the contact interfaces behave similarly, the rows with the highest stress rates may crack first, in order to allow reorganisation of load transfer in the post-elastic phase. The evolution of the stress percolations in the post-elastic phase is crucial for the determination of the load capacity and stability of the structure. The examination of the developed algorithm indicate how dry-stacked wall structures evolve under an increasing vertical force and represent a new tool for investigating the localized and randomly defined internal stress distribution induced by external compression forces.

The shape of the mortarless masonry element may be optimised for higher structural load capacity by having a height-to-length ratio of 1.0. The ratio of 1.0 would be best practice as further restrictions such as block weight and manoeuvrability play a significant role.

Furthermore, the above mentioned simulations pointed out the importance of the global height of the dry-stacked masonry wall. In fact, any added dry-stacked row in the structure implies a decrease of the effective contact area and thus, increases the stress intensity at the joint interfaces. It may be concluded that experimental investigations on dry-stacked systems may only give real indications on the load capacity of the structure, when the number of joint interfaces and h/L ratio of the block is respected: results of experimental investigations on reduced prism specimens may not be extrapolated to full sized walls as they may over-evaluate the load capacity.

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**References:**

1. AGAAJANI, S., WALDMANN, D., SCHOLZEN, F., LOUGE, A. Development and investigation of a new dry-stacked wall system, PhD thesis, University of Luxembourg, 2015

2. OH, K., Development and Investigation of Failure Mechanism of Interlocking Mortarless Masonry System, Philadelphia: Drexel University, 1994.

3. MARZAHN, G., & KÖNIG, G.,. Experimental Investigation of Long-Term Behaviour of Dry-Stacked Masonry. TMS Journal , 9-21, 2002.

4. DRYSDALE, Properties of Azar Dry-Stack Block IV Construction. Ontario: Azar Group Companies, 2005

5. BIGONI, D., Localized stress percolation through dry masonry walls. Part I – Experiments, European Journal of Mechanics A/ Solids 29 , 291-298, 2009

6. BIGONI, D. (2009). Localized stress percolation through dry masonry walls. Part II – Modelling, European Journal of Mechanics A/Solids 29 , 299-307,2009

7. RADJAI, F., Force distributions in dense two-dimensional granular systems, Physical review letters, 274., 1996

8. BRETON, L., & JUSSIEN, N., Un CSP comme comportement d'agent. Application à la résolution d'équations en physique des milieux granulaires. LINA; Ecole des Mines de Nantes.

9. JAAFAR et al., ALWATHAF, THANOON, NOORZAEI, & ABDULKADIR, Behaviour of interlocking mortarless block masonry. Proceedings of the Institution of Civil Engineers - Construciton Materials 159 (CM3), 111-117, 2006

10. ABDULLAH et al., Structural Behaviour of a Mortarless Interlocking Blockwork System. Masonry International, Proceedings of conferences 2007 (pp. 527-532). Universiti Teknologi Malaysia: British Masonry Society, 1995

11. CERVENKA, V., JENDELE, L., & Cervenka, J., ATENA Program documentation Part 1 – Theory. Prague, 2010

12. EDWARDS J. et al., Design and Construciton of interlocking mortarless block masonry. Alberta: Department of Civil Engineering and Environmental Engineering, University of Alberta, 2010

13. GAVRIEL, S., Handbookk of human factors and ergonomics. New York: Wiley, 2006

14. RAMAMURTHY and ANAND, Development and performance evaluation of interlocking-block masonry. Journal of architectural Engineering , 6:45-51, 2000

15. THANOON, J., Development of an innovative interlocking load bearing hollow block system in Malaysia. Elsevier Construction and Building Materials , pp. 445-454, 2004

The following is an abstract of the bachelor thesis describing the work of designing, manufacturing and assembling a mock-up of a device positioning a satellite around an existing ground antenna.

UNIVERSITÉ DU LUXEMBOURG

Prix de la Revue Technique Luxembourgeoise 2015

# DESIGN, MANUFACTURING AND ASSEMBLY OF A MOCK-UP OF A SATELLITE AROUND A PROTOTYPE ANTENNA_

Paul Kremer

In 2013 Laurent Marini built a mock-up of a ground antenna (Figure 1) as it is used by the Galileo navigation satellite system. Equipped with an IR-receiver (camera) in the centre of the reflector, servo motors in the housing behind the reflector and at the bottom of the station, this antenna is able to track a satellite (represented by an IR LED) in space.

The motivation for the work described in this article is to have a mechanism which positions the satellite around the existing antenna autonomously in order to be able to exhibit the whole setup during the „University of Luxembourg Open Day". To do so, a device had to be designed according to a set of requirements, manufactured, assembled and tested during a six month time.

**Requirements**

The following requirements had to be met by the final design:

_Be able to perform a movement that mimics the movement of the Galileo satellite on its orbit
_Work autonomously
_Be easy to disassembly: The device has to be disassembled in order to be relocated or stored
_Elegant appearance: The antenna is considered to be the main object, as such the orbital device should not be too dominant
_Producible at the University of Luxembourg: The manufacturing process had to take place at the University of Luxembourg i.e. with a limited - but highly accessible - amount of equipment

These requirements left quite some room for personal ideas which in the end led to a design capable of doing more than what was actually required.

**The Orbital Ramp**

After evaluating multiple solutions on how to position the satellite with respect to the antenna, a design in form of an orbital ramp (Figure 2) has shown to be the most promising approach. It consists of a semicircle which form the track of the satellite (later referred to as chariot) to move on.
The design was strongly influenced by the manufacturing processes available to this project, amely: Fused Deposition Modeling (FDM), CNC laser cutting and some basic metalworking. It has been chosen to manufacture most of the device using laser cutting of medium-density

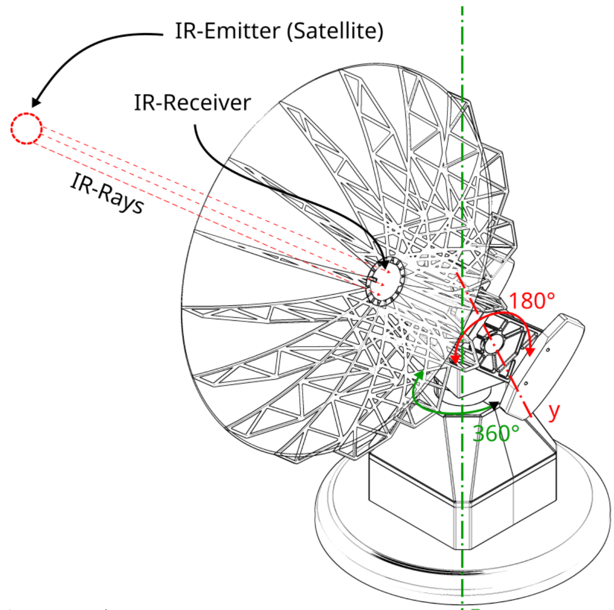


_Fig. 1: Ground antenna

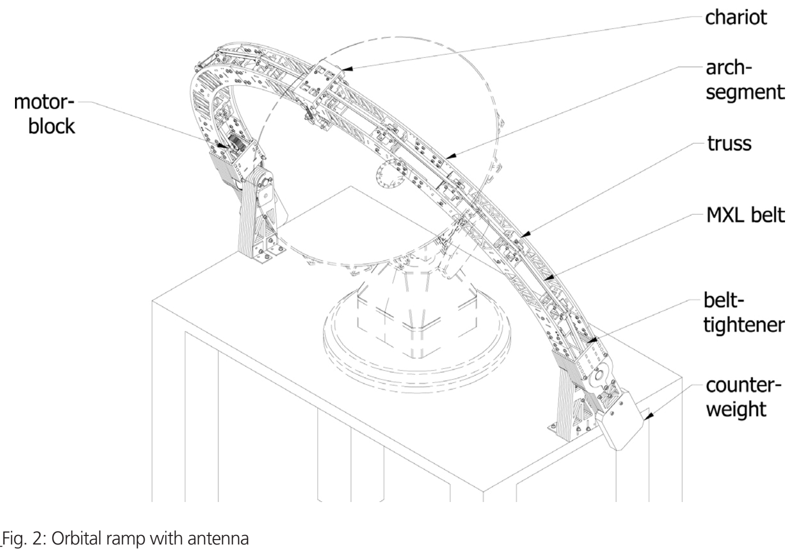


_Fig. 2: Orbital ramp with antenna

In 2013 Laurent Marini built a mock-up of a ground antenna (Figure 1) as it is used by the Galileo navigation satellite system. Equipped with an IR-receiver (camera) in the centre of the reflector, servo motors in the housing behind the reflector and at the bottom of the station, this antenna is able to track a satellite (represented by an IR LED) in space. The motivation for the work described in this article is to have a mechanism which positions the satellite around the existing antenna autonomously in order to be able to exhibit the whole setup during the „University of Luxembourg Open Day". To do so, a device had to be designed according to a set of requirements, manufactured, assembled and tested during a six month time.

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The design consists of 6 major parts: The arch, the two arms, the trusses, the supports, the motor block and the chariot (satellite). The most important building blocks will be presented shortly after.

**The Arch**

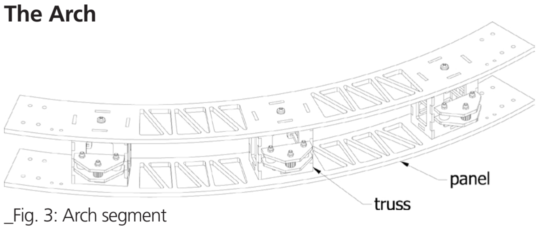


_Fig. 3: Arch segment

The arch is a semicircle divided into three segments (Figure 3) of 60° each due to the limited workspace of the laser cutter as well as to facilitate the storage and handling of the parts later on. This modular design is inspired by the rail of a roller coaster. The side panels are guiding the satellite along its path and offer mounts for the proximity switches detecting the end positions of the chariot. Both panels are interconnected by trusses (Figure 4), resulting in a very stiff system. Moreover they carry and guide the belt along the structure.

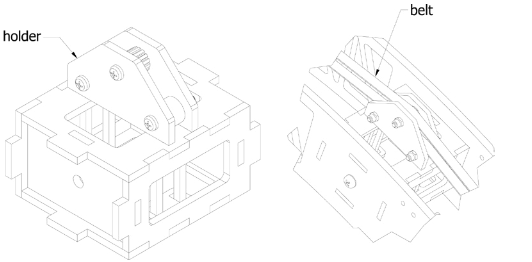


_Fig. 4: Truss

**The Arm**

The arm (Figure 5) forms the link between the supports and the arch. It consists of 14 layers of MDF which are stacked on top of each other. This technique allows building these high volume pieces similar to FDM with the advantage of being much faster.

In the upper part, the arm provides additional mounting space for another function unit like the motor-block or the belt tightener. An internal gear cut in one of the layers enables controlled tilting of the arch with the help of step-per motor located in the support. A counterweight screwed to the arm reduces the load on the teeth of the gear as well as the torque required by the stepper motors. A hole in the middle of the arm acts as mounting point for the shaft via two ball bearings, joining the arm to the support. The geometry permits the arm to pivot about 90° on either side.

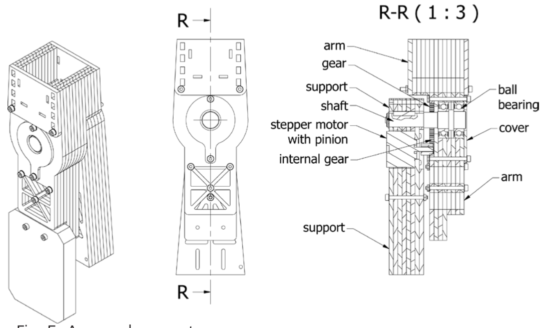


_Fig. 5: Arm and support

**The Motor Block**

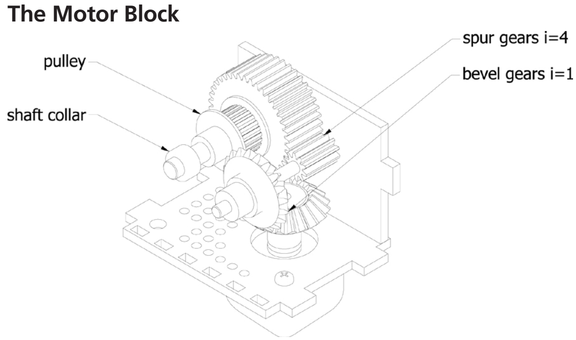


_Fig. 6: Motor block

The motor block (Figure 6) is powering the belt system. Its design had been particularly challenging as it had to be, for aesthetic reasons, entirely contained within the arm. This severely constrained the solution space due to size constraints (52x60x60mm). Using a beefy stepper motor was hence not an option. In fact, the only stepper motor satisfying the space constraints required a transmission ratio of 1:12 in order to be able to move the chariot and to overcome the non-negligible amount of friction in the system.

As a solution to this, a small gearbox has been built consisting of a pair of bevel gears (ratio 1:3) followed by two spur gears (ratio 1:4) which results in a massive increase of torque at expense of overall speed. Losing speed was a valid compromise as movement of the satellite is was expected to be slow anyway.

**The Chariot**

The chariot (Figure 7) represents the satellite moving on the orbital ramp whose trajectory is followed by the ground antenna.

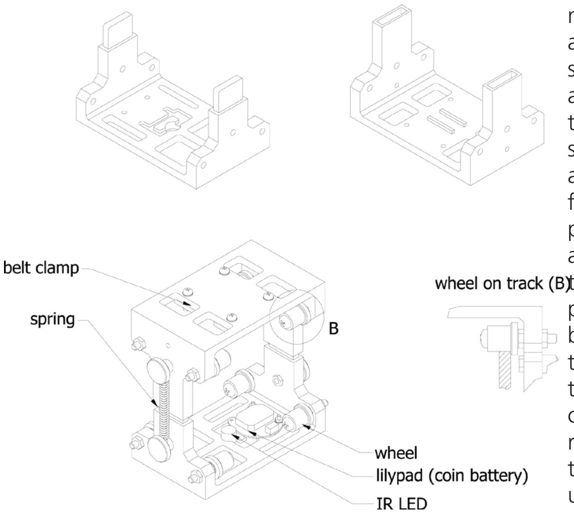


_Fig. 7: Chariot (satellite)

Being manufactured using FDM, the chariot was split into two parts reducing the overall complexity of the model. These parts are joined by sliding connections which, with the help of two springs, are compensating tolerances between the chariot and the track and therefore eliminating play between these parts. Both halves are equipped with small rollers ensuring lateral and longitudinal guidance as well as reducing friction be-tween the chariot and the track. The upper part is connected to the belt using a belt clamp made of MDF.

An IR LED as well as its corresponding electric circuit with the power source (coin battery) are positioned at the bottom of the chariot. The antenna is tracking this IR LED later on.

## Control

The control-part of the device has been pursued in parallel to the mechanics due to strong interdependencies between these two. The requirements were as follows:

_Movement of the satellite has to be smooth in order to prevent jerky movement of the antenna
_Safety: Avoid damage to the device e.g. due to errors of the operator
_Expose position data to the outside word: Useful e.g. to visualize the device's current state in a CAD environment

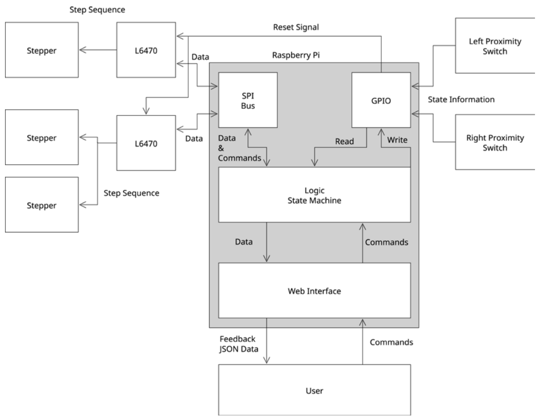


_Fig. 8: Block diagram

In addition to that a user interface and basic programming support had been added. The whole control sys-tem consists of three stepper motors, two stepper drivers (L6470), two proximity switches and a microcom-puter (Figure 8).

Most of the logic is handled by a Raspberry Pi, a small low power microcomputer, which offers a wide range of interfaces to different bus systems such as I2C and SPI. It has enough processing power to handle the control tasks as well as to provide the user with a decent user interface at the same time. The stepper motors are driven by stepper motor drivers controlled by a Raspberry Pi via SPI bus. These drivers are generating the step sequence based on commands coming from the Raspberry Pi. Using these dedicated stepper drivers has been judged necessary as this microcomputer is not well suited for real-time applications. Another big advantage is the ability to use sub-steps (micro-stepping) which greatly re-duces noise emissions and vibrations. In combination with linear acceleration profiles this results in a very smooth movement of all parts. The software running on the Pi is written in C++ and consists of a state machine for the control logic and a local web server for the human device interface. On startup, the device has to perform a startup routine which consists of moving the arm and chariot into zero position (referencing). This is necessary as there are no sensor available which are indicating the absolute position. The zero position of the chariot is easily detectable by the proximity switches mounted at the utmost positions of the arch (approx. 83° from the middle of the arch). Detecting the zero position of the arm involves analyzing the electric current fed into the stepper motors. As soon as the controller raises a flag indicating stall, the controller will assume that the arm has reached its zero position. Afterwards with the use of the calibration data, the device can be operated safely either by the user or by executing a set of motion commands (program).

## Programming

The motion pattern of the orbital device is fully programmable via simple text files containing a sequence of commands which look as follows:

Listing 1 Sample program

```
Run,0,0,50        // move chariot to position 0 at speed 50
Run,1,50,100      // move arm to position 50 at speed 100
Wait,1000         // wait 1000ms
Run,0,100,50      // move chariot to position 100 at speed 50
```

The sample shown in Listing 1 positions the arch vertically and tells the chariot to oscillate between the left and right support. These text files are read, interpreted and executed by the software one at the time in an endless loop. Hence giving the device the possibility to operate fully autonomously with the option to easily change the comands without recompiling the software.

## Human device interface

An embedded web-server is running on the Raspberry Pi providing the operator with a web-interface (Figure 9), facilitating debugging tasks and allowing direct control of the tilt angle and the position of the chariot. A timeline keeps track of the movements of the orbital device. A logbook tracks all the events happening during runtime (e.g. state changes).

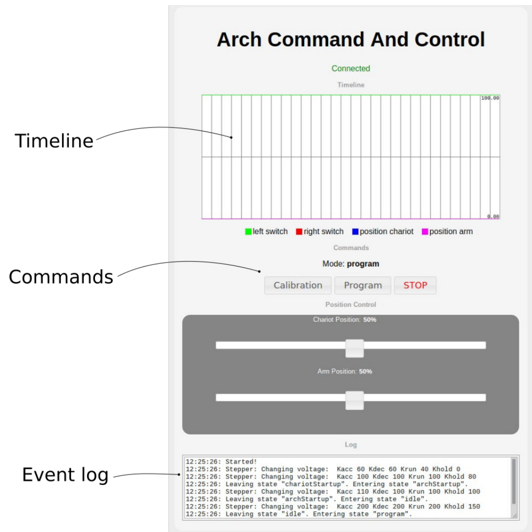


_Fig. 9: User interface (webpage)

The big advantage of a HTML based interface is mainly that it requires no client side software besides a web-browser. Connecting a computer via WIFI or Ethernet to the Raspberry Pi and opening the web browser is all what is needed. In fact even using a smartphone to control the device is very possible.

## Next up

Both the orbital ramp and the antenna work well on their own but they have never been tested together so far. Integrating both systems into a greater system is the last remaining major task and requires careful tuning of both systems.

**Wie sicher sind medizinische Smartphones-Apps? Der Beitrag diskutiert die Bedrohungslage, indem er typische Speicherorte sensibler Daten und die Übertragungswege in einem mHealth-Szenario analysiert. Eine Fallstudie zeigt das Vorgehen und die Ergebnisse einer Sicherheitsanalyse von Android Apps im Bereich Diabetes und Bluthochdruck. Des Weiteren wird untersucht, ob kostenpflichtige Apps besser abschneiden als kostenfreie Apps und welche Rolle bestehende Standards spielen.**

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Hochschule für Technik, Wirtschaft und Gestaltung
University of Applied Sciences

Der Beitrag erscheint auch im Forschungsbericht der Hochschule Trier, vgl. [4].

# WIE SICHER SIND MEDIZINISCHE SMARTPHONES-APPS?_

Prof. Dr. Konstantin Knorr

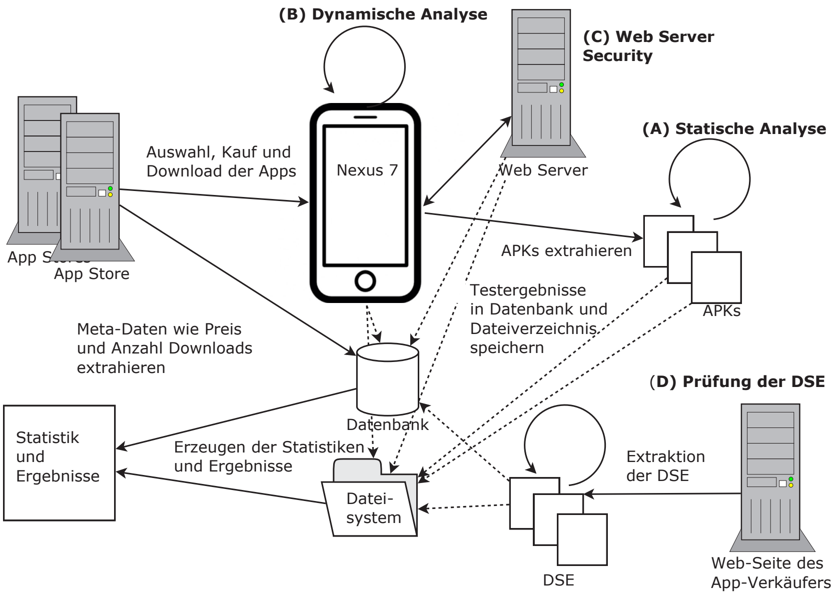


_Abb. 1: Verwendete Methode für die Untersuchung von mHealth-Apps

Mobile Geräte wie Smartphones und Tablets und die darauf laufenden Applikationen (Apps) haben sich in kurzer Zeit global verbreitet. Insbesondere bei mobilen Anwendungen mit Bezug zur Gesundheit und Medizin (mobile Health - mHealth) wie z.B. Apps zur Gewichtskontrolle oder zur Überwachung von Bluthochdruck spielen dabei Überlegungen zum Datenschutz und zur -sicherheit eine immer größere Rolle. Die erhobenen Daten sind sensibel und gelten nach den bestehenden Datenschutzgesetzen als besonders schützenswert. Die Vorteile von mHealth liegen u.a. in der hohen Verfügbarkeit der „Erfassungsgeräte" und der elektronischen statt papierbasierten Datensätze. Andererseits wissen viele Nutzer nicht, ob und wie ihre persönlichen und medizinischen Daten geschützt sind, an wen diese weitergereicht werden und welche Angriffe es gibt.

## Bedrohungslage

Die Apps nutzen alle dem Smartphone zur Verfügung stehenden Kommunikations- und Speichermöglichkeiten. Neben dem internen Speicher werden auch die SD-Karte, der Datenexport über E-Mail, externe Speicherorte (wie Dropbox) oder die Synchronisation mit externen Servern genutzt. Einzelne Apps bieten Benachrichtigungen z.B. per SMS an den Arzt und den Anschluss externer Hardware über NFC (Near Field Communication) z.B. zum Erfassen des Blutzuckers. Ausgewählte Apps bieten einen Export ihrer Daten auf Social Media-Seiten wie Facebook und unterstützen dadurch den Trend zum „Quantified Self".
Ein großer Teil des Netzwerkverkehrs wird für die Einblendung von Werbung und für die Analyse des Benutzerverhaltens verwendet. Der App-Shop weiß, welche mHealth-App ein Nutzer installiert hat, was Rückschlüsse auf Erkrankungen des Nutzers erlaubt.

Weitere potenzielle Angreifer auf die medizinischen Daten eines mHealth-Nutzers sind z.B. Lauscher im Netzwerk, Man in the Middle (etwa bei SSL-Verbindungen), App-Shop-Betreiber, App-Entwickler, Malware, Angreifer mit physischem Zugriff auf das Endgerät, Betreiber von Social Media-Seiten oder Krankenversicherungen. Dies zeigt deutlich, wie schwierig es für einen Nutzer ist, einen Überblick über die Verbreitung seiner medizinischen Daten zu behalten und seine Daten zu schützen.

## Vorgehensmodell

Bei der Überprüfung der Datensicherheit einer mHealth-App müssen neben dem Programmcode der App auch ihr dynamisches Verhalten während der Ausführung und die vom Entwickler im App-Shop bereitgestellte Datenschutzerklärung (DSE) untersucht werden (vgl. Abb. 1).

(A) Statische Analyse: Dabei werden basierend auf der APK (Android Application Package)-Datei neben dem Programmcode z.B. auch das Manifest auf die verwendeten Berechtigungen, die korrekte Verwendung von SSL, gesetzte Debug-Flags, die Verwendung von Verschlüsselung für die Daten, die Verwendung von Werbebibliotheken und die Code-Qualität untersucht. Diese Punkte können werkzeuggestützt durchgeführt werden.

(B) Dynamische Analyse: Die App wird gestartet. Dann werden manuell u.a. folgende Punkte getestet: Können medizinische Daten außerhalb des physiologisch möglichen Bereichs eingegeben werden (z.B. Puls von 500 Schläge/min)? Wohin werden Netzwerkdaten übertragen? Wie sind sie geschützt? Passen die angeforderten Berechtigungen zum Verwendungszweck der App?

(C) Einige Apps erlauben das Backup medizinscher Daten auf einen Web-Server. Hier können u.a. der kryptographische Schutz der Daten während der Übertragung (HTTP vs. HTTPS) und die Stärke der Authentisierung am Server (Password-Policy) getestet werden.

(D) Prüfung der DSE: Neben den Kriterien Existenz, Länge in Buchstaben und Alter/Version der DSE sind vor allem die Vollständigkeit und die „Invasivität" der DSE relevant, die manuell geprüft werden muss.

Weitere Informationen zum Vorgehensmodel finden sich in [1].

## Fallstudie Diabetes- und Bluthochdruck-Apps

Anhand des oben beschriebene Vorgehensmodell wurden 154 Android Apps zur Überwachung des Blutdrucks und des -zuckers untersucht (vgl. [2]). Die wichtigsten Ergebnisse waren:

_Fehlende Verschlüsselung: Alle Apps verzichteten auf eine Verschlüsselung der Daten auf der SD-Karte. Die Hälfte der über das Netzwerk übertragenen medizinischen Daten waren unverschlüsselt.

_Eine Validierung der eingegebenen medizinischen Daten für Puls, Blutdruck und -zucker fand in vielen Fällen nicht statt.

_74 der getesteten Apps beinhalten Werbebibliotheken wie AdMob. Der Name der App wurde oft im Klartext über das Netzwerk übertragen.

_80% der Apps hatte keine DSE, die eigentlich die Anwender vorab im App Store über Datenschutz informieren sollte. Bei den restlichen 20% der Apps waren die DSE meist unvollständig, nicht aktuell oder invasiv.

## Vergleich von kostenlosen und kostenpflichtigen Apps

Welche Rolle spielt der Preis einer App bzgl. Datenschutz und -sicherheit? Diese vielschichtige Frage kann u.a. wie folgt verfeinert werden:

_Welche und wie viele Berechtigungen nutzen die Apps?
_Gibt es eine DSE und wie lang und umfassend ist diese?
_Welche und wie viele fremde Code-Bibliotheken werden verwendet?

Die Fragen wurden anhand von unterschiedlichen Datensätzen mit bis zu 10.000 Android Apps aus der Kategorie „Health & Fitness" aus zwei großen App Stores untersucht. Mit folgenden Ergebnissen.

_Kostenpflichtige Apps brauchen weniger Berechtigungen (4,38 im Gegensatz zu 7,04, vgl. Abb. 2) und verwenden für Werbung benötigte Berechtigungen wie INTERNET („Zugang zum Internet", 76% vs. 95%), ACCESS_NETWORK_STATE (55% vs. 89%), ACCESS_COARSE_LOCATION (17% vs. 33%und READ_PHONE_STATE (26% vs. 38%) deutlich seltener.

_Kostenpflichtige Apps haben seltener eine DSE und deren durchschnittliche Länge ist kürzer. Möglicherweise nutzen Entwickler freier Apps die DSE als zusätzliches Mittel Vertrauen aufzubauen oder für ihre App zu werben.

_Fremdsoftware wird stark eingesetzt (bis zu 27 Bibliotheken pro App). Kostenfreie Apps verwenden den deutlich häufiger Werbe-Bibliotheken als kostenpflichtige Apps (z.B. 45% vs. 20% bei AdMob). Die Code-Qualität sinkt dadurch bei vielen kostenpflichtigen Apps. Beide App-Kategorien verwenden oft veraltete Bibliotheken.

Viele der Unterschiede sind durch ökonomische Aspekte bzw. das App-Geschäftsmodell verschuldet: Ein App-Entwickler hat die Möglichkeit seine Aufwände (1) über den Verkaufspreis, (2) über Werbung in der App oder (3) über In-App Purchases zu finanzieren. Im Falle von (2) hat das unmittelbare Auswirkungen auf die Anzahl und Art der Berechtigungen, auf die verwendeten Software-Bibliotheken und auf die Code-Qualität seiner Apps.

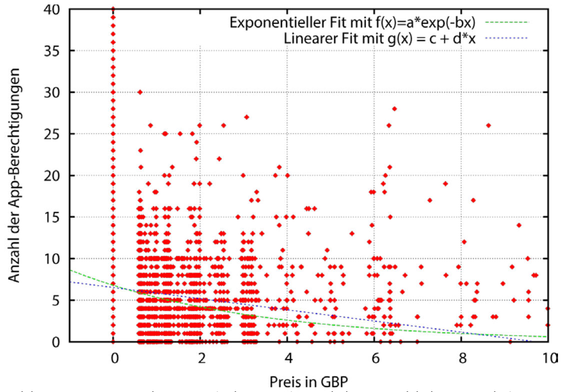


_Abb. 2: Zusammenhang zwischen Preis und der Anzahl der Berechtigung von mHealth- Apps. Jede Raute repräsentiert eine oder mehrere Apps. Kostenpflichtige Apps haben einen Mindestpreis von 0,59GBP

## Standardisierung

Können bestehende Standards, Gesetze und Zertifizierungen dem Nutzer bei der Auswahl von mHealth-Apps helfen? Der US HIPAA (Health Insurance Portability and Accountability Act) adressiert primär Krankenhäuser, Versicherungen und Ärzte, aber nicht Entwickler von mHealth-Apps. Die US FDA (Food and Drug Administration) und die europäische Directive 93/42/EEC regulieren nur einen kleinen Prozentsatz von mHealth-Apps, nämlich die, die als mobiles medizinisches Gerät gelten.

In der EU gibt es die Datenschutzgesetze der Mitgliedstaaten und die über-greifende Data Protection Directive 95/46/EC. Diese Vorgaben werden oft ignoriert, da die technischen Anforderungen generisch und länderspezifisch und die Strafen niedrig sind. Die Common Criteria (ISO/IEC 15408) eignen sich zwar prinzipiell auch für mHealth-Apps, werden aller-dings aufgrund des hohen Aufwands so gut wie nie eingesetzt. Es gibt auch privatwirtschaftliche Ansätze wie z.B. von Truste, die allerdings ebenfalls wenig verbreitet sind. Bestehende Standards und Zertifizierungen eignen sich daher kaum für mHealth-Apps. Sie sind zu kostenintensiv oder greifen nur Teilaspekte heraus. Die Entwickler der Apps fühlen sich daher nicht an diese Vorgaben gebunden und entwickeln die Apps nach ihren eigenen Sicherheitsanforderungen oder vernachlässigen das Thema. Das Fehlen einer Regulierung wird von vielen mHealth-Entwicklern gar als Vorteil gesehen.

## Fazit

Ein sicherheitsbewusster Nutzer befindet sich zurzeit in einem Dilemma: Ihm fehlt eine Möglichkeit, sich über die Datensicherheit der Apps verlässlich zu informieren. Im Vergleich schneiden kostenpflichtige Apps etwas besser ab als kostenfreie. Der Anwender bezahlt die App direkt mit einem Geldbetrag statt indirekt mit seinen persönlichen Daten. Passende Standards und Zertifizierungen existieren noch nicht oder sind nicht geeignet für mHealth-Apps.

Die vorgestellte Prüfung beinhaltet aufwändige manuelle Schritte und kann daher auf die große Masse an Apps nicht angewendet werden. Eine Verbesserung der Situation könnte von den Betreibern der App Shops ausgehen, wenn sie z.B. Apps vorab intensiver auf Sicherheitsaspekte prüfen oder die Abgabe einer DSE für mHealth-Apps verpflichtend machen würden. Zukünftige Arbeiten sollten sich mit einer Verfeinerung und weiteren Automatisierung des Vorgehens und mit der Durchführung weiterer Fallstudien befassen.

**Literatur:**

[1] K. Knorr/D. Aspinall, Security Testing for Android mHealth Apps, Proc. of the 6th international Workshop on Security Testing (SECTEST), 2015.

[2] K. Knorr/D. Aspinall/M. Wolters, On the Privacy, Security and Safety of Blood Pressure and Diabetes Apps, Proc. of IFIP SEC 2015 International Conference on ICT Systems Security and Privacy Protection, S. 571-584, 2015.

[3] K. Knorr, Datensicherheit bei mHealth-Apps, digma - Zeitschrift für Datenrecht und Informationssicherheit. 4/2015, S. 162-165

[4] K. Knorr, Wie sicher sind medizinische Smartphones-Apps? Untersuchung der Datensicherheit und des Datenschutzes von Android mHealth-Apps, Forschungsbericht „Lehre und Forschung 2015",
S. 84-88, Hochschule Trier,
Download unter http://www.hochschule-trier.de/index.php?id=3163

itrust consulting and University of Luxembourg build Security for the Internet of Things (IoT) to the benefit of Smart Mobility, Smart Buildings and Smart Cities. The IoT brings opportunities to create new services and products, reducing costs for societies, and changing how services are sold and consumed.

Boost the Internet of Things (IoT) by laying essential foundation

# EUROPEAN RESEARCH & INNOVATION ACTION PROJECT BIOTOPE_

Dr. Carlo Harpes, Managing Director, itrust consulting s.à r.l.
Ingo Senft, Chief Administrative Officer and Sales Manager, itrust consulting s.à r.l.
Dr. Sylvian Kubler, Senior researcher, University of Luxembourg
Dr. Jérémy Robert, Senior researcher, University of Luxembourg

_Dr. Carlo Harpes and Dr. Sylvain Kubler having exciting discussions about the start of the bIoTope project.

## 1. About IoT

When the University of Luxembourg organised, and the Luxembourg-based SME itrust consulting assisted to the first European Summit On Future Internet in 2010, both organisations were willing to partner with leading experts and scientists to "prepare for a Future Internet that can cope with the demands for generalised mobility, improved security, resilience and trust, the delivery of time-critical and high-bandwidth applications, as well as the emergence of an Internet of Things".

Whereas the traditional Internet allowed computers to communicate over complicated protocols such as UDP or TCP, it enabled people to share electronic messages, so-called emails, and later on, people to publish information over the www and search engine to find whatever they feel useful for their users in this waste web of published information. This Internet is the word of people and their computers, where many other objects would similarly benefit from such communication.

According to Wikipedia, "The Internet of Things (IoT) is the internetworking of physical devices, vehicles, buildings and other items – embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data. In 2013 the Global Standards Initiative on Internet of Things (IoT-GSI) defined the IoT as «the infrastructure of the information society.» The IoT allows objects to be sensed and/or controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit. When IoT is augmented with sensors and actuators, the technology becomes an instance of the more general class of cyber-physical systems, which also encompasses technologies such as smart grids, smart homes, intelligent transportation and smart cities. Each Thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure. Experts estimate that the IoT will consist of almost 50 billion objects by 2020."

In 2016, after multiple preparation work, a European research project, called bIoTope could be launched, as one of the results of these partnerships.

## 2. About bIoTope

bIoTope (Building an IoT OPen innovation Ecosystem for connected smart objects) is a RIA (Research and Innovation action) project funded by the Horizon 2020 programme, Call ICT30: Internet of Things and Platforms for Connected Smart Objects.

bIoTope lays the foundation for open innovation ecosystems, where companies can – with minimal investment – innovate by creating new Systems-of-Systems (SoS) platforms for connected smart objects. To achieve this goal, bIoTope provides the necessary standardised Open APIs to enable the publication, consumption and composition of heterogeneous information sources and services from across various platforms, including FI-WARE, OpenIoT, city dashboards, etc.
This will foster new forms of co-creation of services ranging from simple data collection, processing, to context-driven, intelligent and self-adaptive support of consumers' everyday work and life. bIoTope also establishes a governance roadmap for ecosystem orchestration to properly maintain, grow and sustain the socio-technical and business-wise bIoTope ecosystem. bIoTope develops a dozen of smart city proofs-of-concept/pilots, implemented in three distinct cities/regions (Helsinki, Grand Lyon, Brussels Region).

The diversity of Things communicating and taking advantage of the IoT are well illustrated in bIoTope's appetizer in Figure 1.

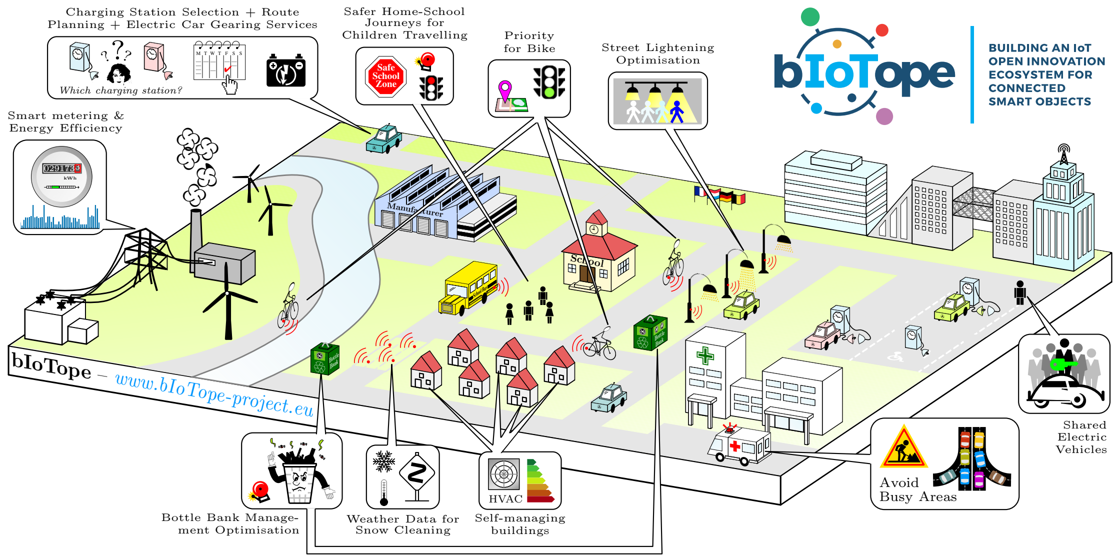


_Fig. 1: Reference picture from: http://www.biotope-project.eu/

## 3. Kick-off of bIoTope

itrust consulting s.à r.l. and the University of Luxembourg announced early this year that they have partnered with a consortium of leading European research organisations, industrial and government technology suppliers, manufacturers, and representatives from multiple European cities to address the complexity of developing new applications and services that exploit today's world where everything is increasingly connected to the Internet.

Supported by the European Commission, the bIoTope project is investing more than €7.8 million to develop a new platform to enable systems utilising IoT concepts to be quickly assembled through technological innovations that allow systems to start small and become increasingly larger and more advanced without the need for costly redesign and redevelopment.

The University of Luxembourg and itrust consulting will work in close cooperation contributing to the work package 3: Building a Secure, Open & Standardised SoS (Systems-of-Systems) Ecosystem for IoT. The University of Luxembourg will contribute to the project with its extensive know-how in IoT interoperability and context-aware computing, while itrust consulting will contribute with its cryptology and security expertise.

The bIoTope project coordinator, Professor Kary Främling, (Aalto University, Department of Computer Science and Engineering) stated that the project brings together Europe's leading experts in system software technologies, smart products, man/machine interfaces, knowledge management and context awareness that will develop new and creative approaches for implementing a Cloud -based platform for providing the core services needed to deliver today's and future IoT systems for government, industry and consumers.

Chief Technology Officer of the bIoTope project is Dr. Sylvain Kubler, senior researcher in the Interdisciplinary Centre for Security, Reliability and Trust at the University of Luxembourg, and the lead writer of the bIoTope H2020 project proposal. He stated that both the project kick-off meeting in Helsinki and the ICT30 kick-off meeting in Brussels stressed that there is a lack of appropriate security and privacy frameworks to cope with the IoT peculiarities and to provide customers with full end-to-end control of their data and ownership, while enabling them to make money out of it (e.g., using digital currency).

In order to address this global lack of security and privacy frameworks, Dr. Carlo Harpes, Managing Director of itrust consulting proclaims that it will be a huge challenge to specify security protocols and in particular to integrate cryptography, create payment functions, access token or privacy protection information and finally implement such Everything-as-a-Service building blocks.

With a view on the overall project scope, it is clear for Prof. Yves Le Traon (University of Luxembourg), that bIoTope will bring solutions to Smart Mobility, Smart Buildings, Smart Air Quality and Smart Cities across Europe.

## 4. Everything-as-a-Service

The core functionalities of the bIoTope ecosystem for IoT will use the latest concepts of Everything-as-a-Service (XaaS), primarily aiming at reducing as much as possible the need to develop custom connectors and, for the end users, to manually connect one service to another.
Everything-as-a-Service can contribute to the publication, consumption and composition of many types of information sources and services for connected smart devices that may be linked to many different types of systems. The bIoTope ecosystem supports advanced modelling of user situations and inference analysis to support compatibility among distinctly different IoT applications and services that are targeting different domains (e.g. government, industry). The ecosystem will offer user-friendly ways to discover, predict, validate and supply relevant information about the current situations of users and devices, enabling IoT applications to customise and adapt services for users.

## 5. Applicability of XaaS in bIoTope

Figure 2 provides an overview of the bIoTope big picture. First, as highlighted through the stage denoted by "0" in this figure, the primary bIoTope's goal is to standardise the way to publish and discover services in the IoT, or Web of Things (i.e., describing in a generic way IoT data generated by domain-/vendor-specific platforms). In this respect, the O-MI (Open Messaging Interface) and O-DF (Open Data Format) standards[1,2] are used, of which a standalone reference implementation is available on GitHub[3]. This reference implementation, which can be set up on any device, allows end-users to publish and potentially monetise one or more services in the bIoTope IoT ecosystem. Examples of O-MI nodes that currently run and expose services related to a smart house (see arrow denoted by "1"), and a smart campus, have been made available[4,5].

1_http://www.opengroup.org/iot/omi/index.htm
2_http://www.opengroup.org/iot/odf/index.htm
3_https://github.com/AaltoAsia/O-MI/
4_http://jeremyshouse.jeremy-robert.fr
5_https://otaniemi3d.cs.hut.fi/omi/node/html/webclient/index.html

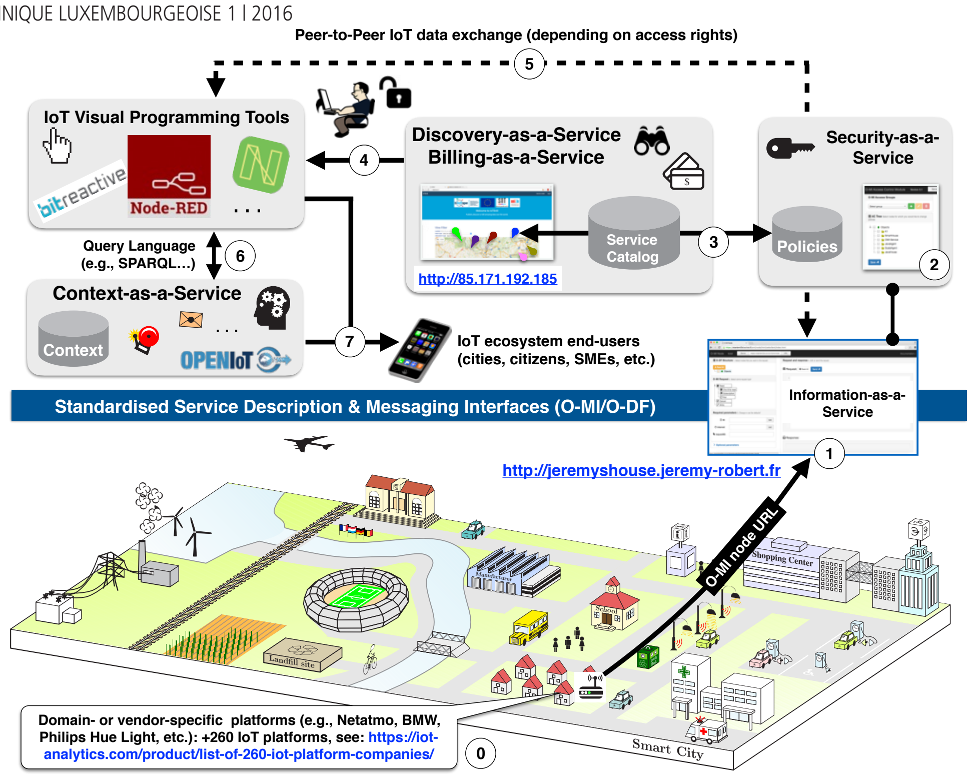


_Fig. 2: The bIoTope big picture and associated XaaS (Everything-as-a-Service) building blocks

bIoTope also provides SECurity-as-a-Service (SECaaS), enabling IoT data producers/publishers to decide what data or services they want to publish in the ecosystem service catalogue, what are the access rights and what using are the costs ideally paid by crypto-currencies. This is symbolised in Figure 2 through Stages 2 and 3. The service catalogue is currently available at its early stage of development[6].

The primary stakeholders targeted in the bIoTope ecosystem are developers (companies, start-ups, SMEs…) who can look for specific IoT data/services available on the marketplace, and once they get the access rights – either O-MI node-related data is available for free or the consumer pays for accessing it during a specific period of time. They can therefore develop their own IoT flows using visual programming tools such as Node-Red[7], NETLab Toolkit, bitreactive (Eclipse plugin), or any other IDE (Integrated Development Environment) tool. All this is summarised through the arrows denoted by "4" and "5". It is important to note, that data is exchanged in a peer-to-peer manner between the service producer and consumer, meaning that no information is stored in a bIoTope Cloud-like solution. More advanced functionalities can be developed on top of it, such as context-brokers able to deliver Context-as-a-Service, e.g. considering two attributes of a living room such as:
(i) number of people present in the room,
(ii) noise level,
the context-broker can tell whether people are working, having dinner, having a party, and so on. Overall, bIoTope opens up opportunities for small and big companies to foster innovation, where such new services can be made available through IoT visual programming tools (when targeting developers) or Apps (when targeting end-users). All this is illustrated through the arrow denoted by "7" in Figure 2.

Such a scenario might easily lead to the misunderstanding that confidential information exchanged is under control of the users. But in reality many questions regarding such data exchange exists: where and how is the data stored, who owns it and so on.

These critical security related issues require an in-depth analysis backed by experience that should result in an adequate, proven and well accepted solution.

For instance, the context-broker should tell whether people are working, having dinner, having a party and so on, but it should not be able to identify the individuals in the room. That means, no person should be directly linked to such data, so that privacy is maintained while offering services.

Another instance would be that a data producer who wishes to monetise over its data, and uses crypto-currencies for payment, should have an assurance that such payment is verified and secure.

There may also be a case where the data generated by a certain device is shared with other users or devices; it must be able to anonymise its identity.

To conclude, it can be pointed out, that bIoTope does not create an IoT platform but rather a solution for creating an ecosystem of platforms, which falls within the Systems-of-Systems paradigm. It is of utmost importance that such an ecosystem incorporates suitable security and privacy modules.

Unlike typical IoT platforms where data is pushed and "siloed", i.e., isolated in one system (often a Cloud-based solution) bIoTope does not store any IoT data but only creates links to such data, which allow to avoid major security and privacy concerns. Indeed, IoT data or services are exchanged in a peer-to-peer manner, where the service provider controls what data goes "out" or "in". In the future, IoT web services like search engines (Google, Yahoo, etc.) will rely on successful IoT ecosystems to index the IoT.

Overall the bIoTope project investigates and evaluates viable and secure architecture design strategies, along with guidelines for future IoT implementations and "Innovation" actions.

## 6. Opportunities and challenges with bIoTope

New IoT applications and initiatives that leverage ubiquitous connectivity and analytics are popping up all across the world. They offer tremendous capabilities for enhanced connectivity, device management, and data management across disparate IoT platforms of different sectors such as transportation, energy, manufacturing, healthcare and city service providers.
Such cross-domain and cross-platform services open up opportunities for disruptive innovation and for new business models, reducing costs for societies while adding new services for citizens. IoT thus will foster a sustainable economic growth.
Nevertheless, IoT is entering a new phase with an increased

6_http://85.171.192.185
7_An O-MI node module for Node-Red is currently being designed

focus on how to avoid the continual emergence of vertical silos, which hinders developers to produce disruptive and added value services across multiple platforms and sectors. At the time of writing, a study reports more than 250 IoT platforms available on the market[8].

As already mentioned, several organisations and standardisation bodies understood that the value of a truly unified IoT ecosystem would be much more than the sum of current existing verticals. From the bIoTope viewpoint, the principles that need to be satisfied to build successful open IoT ecosystems (i.e., a true Web of Things) are:

1_ The web is the IoT platform: no single organisation or company is in control of the web, which removes the threat of a single point of failure. Everyone (large and small IoT players such as SMEs and start-ups) is able to provide any type of service and monetise it without any predefined intermediary;

2_ Data ownership: end-users have full control over their personal data and all data generated by their devices (e.g., to decide to share specific data with specific partner or type of partners in the ecosystem);

3_ Web Service interoperability and visibility: the success of an IoT ecosystem is closely bound to the number of services that are available, and to how easy they can interact. This implies the need to have a universal way both (i) to describe and publish a service or information and (ii) to find those services;

4_ Security and privacy: the user can trust that data is integer, available, and accessible only for agreed purposes.

Overall, a long-term goal is to be able to connect securely Cloud-based data services, while reducing as much as possible the need to develop custom connectors but allow end users to connect services easily.

**7. Outlook**

bIoTope will build a promising infrastructure, a new information highway, and, as they try to integrate security as well as Privacy by Design and Privacy by Default, two concepts required by the recent EU regulation on privacy. Then there shall be traffic, i.e., useful data packages to build useful services, and this will be the topic of upcoming innovation projects.

During the ADaCoR (Advanced Data Collection and Risks) Industry Workshop that itrust consulting and the University of Luxembourg organised from 19th to 21st of April 2016, several actors, such as Luxmetering, vyzVoice, and LuxTrust, explained their need and use of the IoT, and their interest in participating to pilots. The panel members of the ADaCoR Workshop agreed that "cities should be the first to launch such pilot projects, since they have the necessary resources and infrastructure. (…) A lot of effort is still required to raise awareness among manufacturers, providers and consumers.

Dr. Carlo Harpes has a few new services in mind: "Years ago we developed a concept for smart dynamic carpooling, which allows drivers to accept well registered passengers during a trip for which drivers and passenger are brought together thanks to intelligent multimodal navigation. We will analyse how to implement such a service on top of the bIoTope ecosystem and hope to identify other big players to commercialise the service together. And many other ideas may get a chance to succeed..."

**bIoTope objectives**

_Provide the necessary standardised Open APIs to enable horizontal interoperability between vertical silos;

_Enable new forms of co-creation of services ranging from simple data collection, processing, to context-driven, intelligent and self-adaptive support of consumers' everyday work and life;

_Establish a clear framework for security, privacy & trust that facilitates the responsible access, use, and ownership of data in the IoT;

_Develop large-scale pilots in smart cities to provide social, technical and business proofs-of-concept of bIoTope enabled-SoS ecosystems;

_To maintain, grow & sustain the socio-technical and business-wise bIoTope ecosystem, e.g. by establishing an end-to-end governance roadmap for ecosystem orchestration.

http://biotope.cs.hut.fi/

**About itrust consulting s.à r.l.**

itrust consulting, awarded «Start-up of the Year 2008», at Luxembourg's ICT awards, was created in January 2007 to consult public, financial, and industrial customers to protect their information against divulgation and manipulation. itrust consulting applies innovation, participates in research projects (FP7, H2020, ITEA2, Celtic, ESA), and develops norms, security tools and information processing techniques, covering topics like Information Security Management Systems, risk management, penetration testing, digital signatures, cryptology, Internet security, Critical Infrastructure Protection, SCADA, Secure Localisation, data privacy, computer forensics, operates malware.lu CERT. itrust is consulting is alsoalso well accepted for its SECurity as a Service (SECaaS) approach.

itrust consulting will complement and work closely with Uni.lu on security and privacy aspects; itrust consulting has several turnkey products and services that can be deployed or adapted to the bIoTope needs to tackle information security management systems, risk management, penetration testing, digital signatures, or cryptology aspects. itrust consulting will have a key role when investigating new Block Chain technologies and networks such as Bitcoin for «Safe Micro-Billing for IoT».

https://itrust.lu

**About University of Luxembourg and SnT**

The Interdisciplinary Centre for Security, Reliability and Trust (SnT), launched in 2009 by the University of Luxembourg (UL), aims to become a European centre of excellence and innovation for secure, reliable, and trustworthy ICT systems and services. With every passing year, SnT becomes larger and larger that is both an indication of the health of the Centere and a necessary condition for establishing the SnT as a European centere of excellence. SnT targets research and PhD education and provides a platform for interaction and collaboration between university researchers and external partners (industries, government bodies, institutions, and international actors) through its Partnership program. Also, collaborations with European partners play a very important role in SnT development, which is currently being ramped up through a number of new European projects contributing to increaseing its visibility. To date, SnT participated or actively works in more than 30 European projects funded through various programs such as: FP7, CIP, H2020, ESA, EDA, etc...

www.uni.lu

8_https://iot-analytics.com/product/list-of-260-iot-platform-companies/

Academics and practitioners alike have given considerable attention to the measurement of "information" for policy, development and investment decisions. However, this is only possible if we can define what information is and how we can measure it. For the measurement many "proxies" or indicators have been developed using aggregate statistics and the application of largely quantitative methods to gain insights into e.g. e-Readiness, e-Leadership or the "digital divide".

Newcastle Business School (UK)

# MEASURING LUXEMBOURG'S STATE OF ICT DEVELOPMENT_

Nico Binsfeld, Jason Whalley, Newcastle Business School

## 1_ Measuring information – a "grand challenge"?

Taylor (2006) provides an introduction into the history of these proxies starting in the early 1960s and the ongoing search for different information age indicators which were subsequently called information technology indicators including telecommunications, the internet, broadcasting and computing technology.

He notices that most of these indicators use statistical analytics to correlate multiple factors in order to identify relationships between information stocks, information flows and technology as well as other economic and social factors.

Most of these indicators use various national and international empirical data sources. A major concern is the question how to group these factors and how to define their relative weightings[1] and how to build combinations of these.

Taylor also discusses the essence of information and its characteristics and identifies information as a process, information as knowledge and information as a thing.

He moves on to discuss what it means to measure information comparing the process of measuring information to the evolution of physics from a Newtonian to a Quantum based approach.

He concludes that "the identification of approaches likely to yield meaningful data for developing an exploratory and predictive understanding of the interactions of key information proxies with other selected factors in the human environment" constitutes a "grand challenge" which involves some or all of the following:

_Development of some initial theories and models
_Identification of information indicators appropriate to the assigned goal(s)
_International standardization of data collection formats
_Establishment of uniform methods of data collection
_Creation of a public centralized and standardized data recording facility
_Making data conveniently and reasonably available to researchers
_Review and comparison of available statistical tools for data analysis to find those which can appropriately be used to test certain theories
_Generation of testable hypotheses regarding impacts and interactions of the information sector with economic, social, cultural and governmental factors
_Creation and testing of uniform instruments, research designs, and research data bases
_Development of multi-dimensional models which are empirically testable over time, in different places, and at different scales
_Continuous application and refinement of these models in real-world situations

He subsequently (Menou & Taylor, 2006), (Taylor & Zhang, 2007) argued for an organised collective effort and the development of a "coherent academic field of study" and in a first step to "establish mechanisms by which the relevant documents and data sets could be more easily accessed, the various approaches systematically mapped, those interested could meet and exchange ideas and develop cooperative ventures, and stakeholders could discuss their needs and appraisal of the instruments and findings".

The objective of this paper is to introduce elements of this field of study and their application in the specific case of Luxembourg.

## 2_ Research questions and methodology

The objective of the remainder of the document is to address the following two questions:

_How is Luxembourg positioning itself with regards to main international ICT related indicators?
_How has its position/situation evolved over time?

From the answers to these two questions, a summary assessment about the current state of development of the Luxembourgish ICT ecosystem will be provided and proposals will be made for further research[2].

In order to address these two questions, the authors will first identify the available national and international sources of information and ICT indices and discuss their underlying methodologies, their general limitations and their particular limitations in the specific context of Luxembourg.
When available, data will compiled into a time series and/or comparisons will be made with neighbouring countries as well as some countries that are generally considered to be successful in the ICT domain.
The analysis will rely entirely on secondary and publicly available data. There is also a wide range of commercial reports and analysis available on the subject, but these have been excluded due to access limitations.

1_E.g.by expert's opinions or some elaborate statistical methods like e.g. Structured Equation Modelling (Hair, Black, Babin, & Anderson, 2010).

2_Which the first author will undertake as part of his DBA project

### 3_ Indicators to assess Luxembourg's position

In this section, the authors will focus on a specific presentation of several relevant data sources and indices as well as their underlying methodology and discuss their advantages and potential limitations in the context of measuring Luxembourg's ICT developments.

### 3.1_ ICT Sector definition

In order to define the scope of the analysis, the 2007 OECD (OECD, 2011b) definition of the ICT sector will be used. OECD divides the sector into: ICT manufacturing, ICT trade and ICT services using revision 2 (NACE rev.2) of the statistical classification of economic activities in the European Union (Mas, Robledo, & Perez, 2012). This might lead to some potential inconsistencies when looking at time series including data older than 2007. It should also be noted that a different statistical classification is used by the United Nations[3] but methods exists to convert between the different classifications.

### 3.2_ National frameworks and data sources

#### 3.2.1_ An initial ICT snapshot

Service des Médias et des Communications[4] together with the Ministry of Economy and Foreign Trade[5] and ICT Luxembourg[6] published a summary overview about Luxembourg and ICT (Service des Médias et des Communications, 2013).

This publication aims "to provide a snapshot of the ICT sector in Luxembourg based upon the latest statistics and benchmarks available at the time of publication, without pretending to be exhaustive. The data sources are key national and international organisations that were considered representative of Luxembourg's progress in the digital society. A voluntary choice was made in the selection of countries that Luxembourg is compared with. Besides Luxembourg's direct neighbours Belgium, France and Germany, the following countries have been chosen as they are considered the most competitive ICT nations worldwide: Ireland, Japan, the Netherlands, South Korea, Switzerland, the United Kingdom and the USA".

It contains a general overview of Luxembourg's geography, economy and society, detailed figures and comparisons on available infrastructure and connectivity, information and communication services, e-skills, innovation as well as Luxembourg's position on major ICT indices. The first author was part of the team in charge of elaborating this document[7] and it should be noted that while the information is factually correct, because the aim was to promote Luxembourg on an international scale, only those indicators have been included on which the country performs well and the publication does not claim academic rigour nor completeness or objectivity. It nevertheless provides a good starting point and contains a lot of useful information which will be referred to on several occasions below.

#### 3.2.2_ National Regulatory Authority's annual statistical reports

Since 2003, the National Regulatory Authority (Institut Luxembourgeois de Regulation, ILR[8]) publishes every year an annual statistical report about the state of the telecommunications market in Luxembourg. It presents: the total size of the telecommunications market, the share fixed/mobile networks, the share between incumbent and alternative operators, state of internet and broadband access according to technologies any many other but purely telecommunications related factors. Due to space limitations and the lack of comparisons with other countries, the authors will only use the most recently available report (ILR, 2013).[9]

It should be noted that ILR collects the underlying information directly from the different telecommunications operators and service providers in the form of annual reports that they are legally forced to provide. Only the "regulated[10]" services are presented in ILR's reports so that the published annual accounts of the different operators may show different figures[11]. Information about satellite communications, broadcasting and other electronic media are excluded but these may represent an important element of the local market with large international players e.g. RTL Group[12] and Société Européenne des Satellites[13] operating out of Luxembourg.

#### 3.2.3_ National Statistics Office' studies

The national statistical office[14] (STATEC) produces an annual review (Statec, 2012c) (Statec, 2012b) of the Luxembourgish economy which also contains (limited) information about the ICT sector focussing largely on the use of IT by individuals and enterprises. They also publish a complete repertoire of all enterprises active in the ICT sector as defined above (Statec, 2012a). In addition, they have published some specific studies about the evolution of the usage of ICT and the internet over time (Airoldi, 2012), (Frising & Niclou, 2012), (Frising, 2013).

They collect information for other organisations like Eurostat in regular annual surveys. A mandatory self-administered questionnaire is sent out to a population of about 3500 enterprises of more than 10 employees[15].

### 3.3_ Assessments at European Union level

EU member states are required to provide the outcomes of their local evaluations as mentioned above to Eurostat and different European Commission Units in order to establish on an annual basis a comparison of the state of development of ICT within the different member states.

#### 3.3.1_ Eurostat

Eurostat[16], the European Statistical office, tracks the usage of ICT and more specifically, monitors the completion of a single European information space, innovation and investment in ICT research and the achievement of an inclusive European information society. These aspects correspond to the aims of i2010[17] – a European Information Society for growth and employment. This is an EU wide strategic framework for the information society and a key element of the renewed Lisbon Strategy[18], and it offers a comprehensive strategy for the ICT and media sector.

Eurostat provides EU member states with a standardised methodology (Eurostat, 2013), (Eurostat, 2011) for the collection and statistical treatment of the data in order to allow EU-wide comparisons. Data are collected on both households and enterprises and the framework is adapted on a regular basis in order to take into account the rapid pace of technological changes. The following main areas of indicators are published on a yearly basis: policy indicators for benchmarking digital Europe and the use of ICT by public services, telecommunications indicators focusing on mobile phones, E-commerce use by individuals and enterprises, the use of computers and the internet by individuals and business, E-skills of individuals and enterprises. They also provide a regional breakdown of these indicators. A summary of the main statistical findings, the data sources and availability, as well as the relevant publications and methodology (including links to the underlying databases) can be found in Eurostat (2012).

Initially the focus has been on access and connectivity but the scope has been extended over time to include socio-economic analysis such as gender and age specificities or educational and employment differences.

#### 3.3.2_ European Commission

In 1990, the European Commission (EC) initiated a process of liberalisation of the telecommunications industry and the creation of a single European Market for such services with a first directive (European Commission, 1990) followed by several updates and adaptations[19]. Liberalisation actually started to happen as of 1997 and the European Commission produces since then an annual implementation report focusing on the evolution of the telecommunications market and the implementation of the EU directives in a given country e.g. (European Commission, 2010c), (European Commission, 2012b).

Contributing to the global effort to develop appropriate frameworks for measuring the information society, EC has sponsored different research programs over time that came up with several specific composite indices. Thus for example, the SIBIS[20] project (European Commission, 2003) (Empirica, 2002, 2003) proposed a set of 134 indicators on internet readiness

3_See http://unstats.un.org/unsd/cr/registry/isic-4.asp accessed 6.6.2013

4_See http://www.mediacom.public.lu/ accessed 6.6.2013

5_See http://www.eco.public.lu/ accessed 6.6.2013

6_See http://ictluxembourg.lu/ accessed 6.6.2013

7_Representing ICT Luxembourg

8_See http://www.ilr.public.lu/ accessed 6.6.2013

9_Further information can be found in (Binsfeld et al., 2013) a draft paper for presentation at the 24th European Regional Conference of the International Telecommunication Society in October 2013

10_Fixed, mobile voice, broadband and ultra high broadband accesss, cable TV

11_E.g. telecommunications figures shown in the incumbant operator's annual report http://www.pt.lu/portal/lang/en/Entreprise/pid/4980 accessed 10.6.2013

12_www.rtlgroup.com accessed 10.6.2013

13_www.ses-astra.com accessed 10.6.2013

14_http://www.statistiques.public.lu/en/index.html accessed 13.7.2013

15_For details see https://circabc.europa.eu/sd/d/fad1d595-f967-4bf9-9543-6ecfcb650f43/isoc_sdds_lu.htm accessed 13.7.2013

16_http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home accessed 13.7.2013

17_http://europa.eu/legislation_summaries/information_society/strategies/c11328_en.htm accessed 13.7.2013

18_http://www.europarl.europa.eu/summits/lis1_en.htm accessed 13.7.2013

19_See (Binsfeld et al., 2013)

20_http://www.sibis-eu.org/ accessed 13.7.2013

21_http://www.europarl.europa.eu/summits/lis1_en.htm accessed 13.7.2013 and digital divides, information security, perceptions and possible access barriers, digital literacy, learning and training, E-commerce, E-work, E-government, E-health and E-science. However, this index was only published twice in 2002 and 2003. It was followed by the so-called eEurope2005 index (INSEAD, 2005) which was developed as part of the overall assessment of the progress of the Lisbon[21] strategy (World Economic Forum, 2008, 2010).

In 2009, the High Level Group in charge of evaluating and reviewing the Lisbon strategy defined a new conceptual approach for the measurement of the information society and suggested new areas for investigation as well as a list of relevant key indicators (i2010 High Level Group, 2009). The proposal was to assess the development of ICT and its impact through a supply, use and impact framework measuring:

_efficiency gains in the production of ICTs that may translate into a growing contribution of the sector to economic growth and into falling prices of ICT goods and services (supply);
_decreasing prices to stimulate investment prompting the take-up of ICTs by individuals, businesses and the public sector: take-up can further be described through readiness and use of ICT services and content applications (use);
_diffusion of ICT contributes to the sustainable growth of the economy and to jobs, the efficiency of the public sector and the well-being of the population (impact).

It was proposed to use this model for a 2011-2015 benchmarking framework. Eurostat surveys represent the main source of statistical information, with additional data provided by the Communication Committee. The ICT use surveys kept the previously existing structure, including core indicators for tracking development over time. For specific policy needs, ad-hoc surveys/studies have been foreseen. It is based on this new framework that EC published the so-called digital competitiveness reports in 2009 and 2010 (European Commission, 2009), (European Commission, 2010b).

In March 2010, as a reaction to the economic and financial crisis in 2009 and acknowledging that the Lisbon strategy was not enough, EC launched the Europe 2020 Strategy to "exit the crisis and prepare the EU economy for the challenges of the next decade". An important part of this strategy was identified as the "digital agenda for Europe" (European Commission, 2010a) set out to define the "key enabling role that the use of ICT will have to play if Europe wants to succeed in its ambitions for 2020".

The declared objective of this "agenda" is to chart a course for maximising the social and economic potential of ICT, most notably the internet, a vital medium of economic and societal activity: for doing business, working, playing, communicating and free expression. A set of indicators, called digital agenda scoreboard was defined to measure progress on this agenda (European Commission, 2013d) (European Commission, 2013c) . Since then the scoreboard has been published in 2011, 2012 and 2013 (European Commission, 2011, 2012a),(European Commission, 2013b). It contains elements of the previously discussed indices as well as the implementation reports and addition ad-hoc special topics. It can be considered as the most comprehensive assessment of the state of ICT development in the European Union.
This scoreboard gives a lot of visibility to the different member states and respective governments will try to present their countries in the best possible way in order not be left behind or be on the "wrong" side of the digital divide within the EU. A lot of the underlying information is collected through Eurostat and the so-called communications committee[22] from national statistical offices and national regulatory authorities. Therefore care needs to take when interpreting these data.

### 3.3.3_ Digital divide within the EU?

With the extension of the EU towards Central and Eastern Europe, it became important to understand whether there were any differences in terms of ICT development between "old" and "new" member states. This lead initially to the so-called Digital Divide Index (DIDIX) (Selhofer & Hüsing, 2002) (Hüsing & Selhofer, 2004) (Hüsing, 2004).
More recently, Cruz-Jesus, Oliveira, & Bacao (2012) addressed this question for the period between 2008 and 2010 (during the economic crisis). They used underlying data from the digital agenda framework and multivariate statistical methods (factor and cluster analysis). They identified two latent variables (ICT infrastructure and adoption by population and e-business and internet access costs) and identified 5 different groups of countries (digital leaders, digital followers, digital laggards and firm-side low access focussed, individual side-focussed). Their analysis pointed out that the digital divide does actually exist even within the EU and is influenced by economic asymmetries but also by the year of entrance in the EU. In some countries the divide is narrowing but not for all. The analysis is based on only 16 underlying variables and does not take into account any regional differences within a country and is only available for a restricted period of time.

### 3.4_ International Organisations

Several international organisations or sub-organisation from United Nations also collect information about ICT development. Their main objectives are twofold: to establish a broad picture with almost all countries in the world in order to identify clusters of these in terms of developed or developing countries and to identify potential policies that governments or regulators might pursue in order to improve their countries' positions.

#### 3.4.1_ World Economic Forum

In 2001, the World Economic Forum (WEF) published for the first time the so-called Networked Readiness Index, developed by Havard Business School with a survey of 75 countries. As of 2002 (Dutta, Lavin, & Fiona, 2003), this survey was extended and coordinated by INSEAD and is published on an annual basis along with comments and discussions of various topics in the so-called Global Information Technology Report (Bilbao-Osorio, Dutta, & Lavin, 2013). A set of variables is collected and divided in to 4 sub-indexes on the general political, regulatory, business and innovation environment, readiness defined in terms of infrastructure and digital content, affordability and skills, usage by individuals, businesses and government and since 2012 economic and social impacts (Dutta & Bilboa-Osoria, 2012).

The set of indicators is based on quantitative data from Eurostat, ITU, World Bank and others but also on qualitative surveys and interviews that are conducted on a global scale by local partner organisations. The exact number of indices as well as the split between survey and statistical sources varies from year to year as well as the number of countries included in the survey. A ranking is established based on the combination of the different sub-indexes not considering any specific weighting (other than the number of indicators per sub-index). WEF does not provide all of the details of their underlying methodology which makes it difficult to replicate the results and gives WEF a "competitive advantage".

The NRI is a very popular tool for policy and business decisions as well as comparisons between different countries. It is well documented in the media as it provides a single composite indicator to measure ICT performance and to establish a country ranking. Nevertheless it has received a lot of critiques. Thus Goswami, (2006a) questioned the relevance of some of the underlying indicators and identified some that are missing e.g. degree of competition in the market, performance of the NRA. Luyt (2006) questioned the whole idea of a competitive ranking between different countries and commented that the business aspects seem to be more prominent than individuals. The Austrian NRA (RTR, 2011) discusses the scaling between 1 and 7 of most of the indicators and the fact the category between 0 and 1 and between 6 and 7 is not achieved. They also questioned the "objectiveness" of the surveys conducted by the local partners as these can have an important impact on the outcome of the

22_https://ec.europa.eu/digital-agenda/en/communications-committee accessed 13.7.2013 study. On the other hand, some of the indicators are very difficult to influence by political or business decisions and some might take a long time before changes can actually be measured. The implicit weighting of the different indicators is also a matter of critiques, for example in the 2010 version only 3 indicators were used to measure usage of governments as opposed to 16 for businesses and 17 for individuals. For some indicators the measurement range varies from year to year as it is set by the lowest and the highest value achieved in a specific year. Additional problems arise with the ranking as a confidence interval (two standard deviations) has to be considered which is dependent on the actual sampling size. Sometimes the absolute differences between countries are very small and thus the ranking may not be statistically correct.

**3.4.2_ International Telecommunications Union**

The international telecommunications Union[23] as part of United Nations has a long history of measuring telecommunications in terms of the fixed phones lines, minutes of communications and their prices etc. With the technological evolution it had to develop these indicators into a more general of measures of the Information Society. In doing so it collaborated with many other UN and international organisations[24] and similarly to European Commission the indicator framework evolved over time. Much of this work was done within the framework of the World Summit on Information Society[25] (ITU, 2011c),(World Summit on the Information Society, 2005) and the Partnership on measuring ICT for development (Partnership on measuring ICT for development, 2012) that was set-up as part of the WSIS processes.

As part of these activities, the "Core ICT indicators" a common initiative by OECD, ITU and UN to harmonise indicators in order to allow international comparisons, were identified. A discussion about these is provided for example in Goswami (2006). This set contains 41 indicators in 4 categories namely: ICT infrastructure and Access, Access to and use of ICT by households and individuals, use of ICT by Business and indicators on the ICT sector and trade in ICT goods. He also highlights some of the major pitfalls when defining e.g. quality of service, defining what is meant by broadband, setting up price baskets, using or not purchasing power parity and identifying peer groups and illustrates some of the main challenges with data collection. Further details can be found in (UN, 2005a) and (UN, 2005b).

In 2009, ITU decided on a single index, the so-called ICT Development Index (IDI) measuring 11 Information and Communication Technologies indicators for over 150 countries, and calculating its value for 2002 and 2007, so that comparisons could be made. The ICT Development Index (IDI) is a merger of two previous indices: the Digital Opportunity Index and the ICT Opportunity Index. From the DOI it takes indicators related to households and broadband and the methodology and presentation, while from the ICT-OI it takes indicators related to skills, the normalization method and the digital divide analysis and methodology.

This merger responded to the proposal and need of the ITU and other international agencies to concentrate all efforts in just one multi-purpose measuring device, instead of having several complementing indices fostered by different organizations. But, while some consensus has been reached, the cost of is that the new index has evolved towards a lowest common denominator, losing for example the information that affordability brought to. This way, the new index is more polarized and is mainly intensive in infrastructures and just shyly on usage and skills, leaving a big void in all other aspects of digital life: the ICT sector, digital skills or the legal framework. In order to address this limitation, ITU has also defined an ICT price basked (IPB) that measures affordability of fixed, mobile and broadband internet services.

It is important to highlight that, unlike many other indices, the coefficients of the weights assigned to each indicator and sub-indices are calculated statistically, using principal components analysis. The index consists of 5 access indicators weighted 40%, 3 use indicators weighted 40% and 3 skills indicators weighted 20%. Detailed administrative and statistical procedures on the collection and treatment of the different indices can be found in (ITU, 2011a) Both IDI and IPB have since 2009 been published on an annual basis (ITU, 2009), (ITU, 2010), (ITU, 2011b), (ITU, 2012).

Critical comments have been made e.g.(RTR, 2011) about the fact ITU has not defined an absolute maximum value per index but calculates this on a rolling basis by taking the mean value plus twice the standard deviation. Thus countries' individual values may be higher than the "ideal" value. Unfortunately, ITU is not able to publish their index on an annual basis as in particular developing countries have difficulties to collect all of the underlying data. This implies that there may be a considerable delay (up to 2 years) between the collection of data and publication of IDI or IPB.

**3.4.3_ Organisation for Economic Co-operation and Development**

The Organisation for Economic Co-operation and Development (OECD) publishes a set of 15 key ICT indicators[26] which are updated at regular intervals and for which time-series may be available back to 1997. They also provide detailed indicators (OECD, 2011b) on the development of broadband in terms of penetration, usage (individuals, businesses), coverage and geography, prices, services and speeds[27]. The underlying methodologies are well documented in a series of so-called digital economy papers and two bi-annual publications, the communications outlook (OECD, 1999, 2001, 2003, 2005, 2007, 2009, 2011b, 2013) and the information technology outlook (OECD, 2000, 2002, 2004, 2006, 2008, 2010), since 2012 called the internet economy outlook (OECD, 2012b). While the first on focusses on infrastructure and access, the second discusses more the actual usage and socio-economical aspects of ICT. Both documents do also include a section on broadcasting and media infrastructures and include direct access to the underlying data. The statistics used and the methodology applied are well documented. The sources of information tend to be largely similar to the ones mentioned above ie Eurostat, ITU, World Bank and there is a large overlap with some of the publications by these organisations.

**3.4.4_ World Bank**

In addition to contributing to the above mentioned work (The World Bank, 2012b) and producing an annual update of the "World Development Indicators"[28], the World Band also produces an index to measure the so called "Knowledge Economy"(The World Bank, 2008), (Chen & Dahlman, 2005). The application of knowledge, as manifested in areas such as entrepreneurship and innovation, research and development, software and design, and in people's education and skills levels, is increasingly recognized to be one of the key sources of growth in the global economy.

The Knowledge Economy Assessment Method (KAM) was designed as a proxy for a country's preparedness to compete in the knowledge economy using 148 structural and qualitative variables. The comparison is undertaken for a group of 146 countries, which includes most of the OECD economies and more than 90 developing countries. The KAM methodology takes a cross-sectoral approach, allowing the user to take a holistic view of a wide range of relevant factors rather than just focusing on one area. The variables serve as proxies for the 4 pillars of the Knowledge Economy framework i.e. an economic and institutional regime to provide incentives for the efficient use of existing and new knowledge and the development of entrepreneurship; an educated and skilled population to create, share, and use knowledge well; an efficient innovation system of firms, research centres, universities, consultants and other organizations to tap into the growing stock of global knowledge, assimilate and adapt it to local needs, and create new technology and the underlying Information and communication technology to facilitate the effective creation, dissemination, and processing of information.

Included in the KAM are also several variables that track the overall performance of the economy. These variables help to illustrate how well an economy is actually using

23_http://www.itu.int/fr/Pages/default.aspx accessed 13.7.2013

24_For example http://www.orbicom.ca/en/ accessed 13.7.2013

25_http://www.itu.int/wsis/basic/about.html accessed 13.7.2013

26_http://www.oecd.org/internet/ accessed 13.7.2013

27_http://www.oecd.org/internet/oecdbroadbandportal.htm accessed 13.7.2013

28_http://data.worldbank.org/data-catalog/world-development-indicators accesed 13.7.2013 knowledge for its overall economic and social development. The KAM offers several pre-set display modes for simple visual representations of a country's Knowledge Economy readiness. A country can be assessed and compared with others on the aggregate performance on each of the KE pillars or the overall Knowledge Economy and Knowledge indexes for 1995, 2000 and the most recent available year. The KAM also makes possible customized country analysis and cross-country comparison on different indicators.

**3.5_ Commercial organisations**

In addition to the public sources mentioned above[29], there are many commercial initiatives and studies. These are mentioned here for completeness but most of these are either not accessible for academic purposes or do not contain information about Luxembourg.

**3.5.1_ E-readiness rankings by the Economist Intelligence Unit**

The Economist Intelligence Unit published up to 2010 an annual index (a bit similar to NRI) of e-readiness rankings (EIU, 2010). This was focussing on about 60 developed and large economies and used about 100 quantitative and qualitative measures organised into connectivity and technology infrastructure, business environment, consumer and business adoption, social and cultural environment, legal and policy environment and supporting e-services. Unfortunately there is not detailed description of the methodology available and its variables have changed a view times making historical comparisons very difficult.

**3.5.2_ Nokia Siemens Networks' connectivity scorecard**

Similarly the telecommunications equipment provider Nokia Siemens Networks[30] has published the so-called connectivity scorecard (Waverman, Dasgupta, & Rajala, 2011) focussing on the "useful connectivity", Whilst the underlying methodology has been well documented, it does unfortunately not include Luxembourg.

**3.5.3_ Cisco Broadband Quality Score**

CISCO[31] published, together with Oxford Business School, on 3 occasions (Cisco & Saïd Busines School, 2008, 2010) their "Broadband Quality Score" classifying countries into "ready for tomorrow, comfortably enjoying today's applications, meeting the needs of today's applications, below today's application threshold and basic apps". Whilst Luxembourg has been include in the studies, the underlying methodology has not be documented.

**3.5.4_ The Digitisation Index**

The consulting company Booz&Co[32] published on two occasions the "digitization index (DI)" focussing on 15 major economies in the world. The underlying methodology is similar to NRI and Luxembourg was not included in a first go (Sabbagh et al., 2012), (Friedrich, Stroh, & Vollmer, 2012).

Recently, this "DI" was extended and updated (Raúl L Katz, 2013), (R.L. Katz & Koutroumpis, 2013). The "new" digitization index "consists of six elements and twenty-three indicators measuring tangible parameters of perceived digitization metrics. Ubiquity, refers to the adoption of mobile and fixed broadband networks accounting for broadband accessibility and ownership of data devices, such as PCs. Affordability, is essential and derives from the relative access costs of providing such access. Reliability, of networks depends on the annual network investment per subscriber and the faults reported per line.

Speed, is measured by the performance of country level international links and the capacity of wireline 'last mile' offerings. Usage, is a key component of digitization and includes the utilization and adoption of all commercial activities, government services, social media adoption and data usage. Skills, contribute to digitization both in terms of development of local service offerings and usage capacities". The underlying databases are similar to IDI and NRI and the methodology has been well described in the literature. The assessment was extended to 150 countries over the period from 2004 to 2010 and Luxembourg has been included.

**3.6_ Measuring the internet**

With the evolution of broadband connectivity, the internet becomes more and more a critical part of the information society and many applications and services rely on it e.g. Voice over IP, IP-TV, Could storage, On-line gaming, Online applications etc. It is therefore necessary to develop new indicators and measurements to assess the development of the internet and the role of the different national economies on this respect.

Lehr (2012) discussed some of these issues in an OECD working paper and also presented the underlying problems in measuring broadband quality (Bauer, Clark, & Lehr, 2010). They also discuss some of the current approaches (Arbor Networks, 2012; Sandvine, 2013) providing some attempts to better understand internet traffic flows and security issues. OECD, in its most recent Communications Outlook, discusses this topic and proposes IP addresses, web servers, autonomous systems and domain names as measurement units (OECD, 2013).

**3.6.1_ The web index**

The World Wide Web Foundation published in 2012 the so called Web Index[33]. It covers 61 developed and developing countries, incorporating indicators that assess the political, economic and social impact of the Web, as well as indicators of Web connectivity and infrastructure. Much of the Web research that exists today measures quantifiable metrics, such as the number of Web users, speed of access to the Web, the number of broadband subscribers, or covers particular single-dimensions such as economic impact or censorship. However, it is also important to understand how the Web impacts social, developmental, economic and political dimensions as well. By compiling data across many different dimensions of Web health and making it freely available, the Web Index, covering a time period from 2007 to 2011, is intended deepen and broaden understanding of how countries can maximise the impact of the Web.

The Web Index assesses the use, utility and impact of the Web by measuring and ranking:

_Web Readiness: The Index examines the quality and extent of Communications Infrastructure (facilitating connectivity to the Web) and Institutional Infrastructure (policies regulating Web access and skill and educational levels enabling the full benefit of the Web).

_Web Use: The Index looks both at Web usage within countries (such as the percentage of individuals who use the Internet) and the content available to these Web users.

_The Impact of the Web: The Index uses social, economic and political indicators to evaluate the impact of the Web on these dimensions. This includes measures of social networks, business internet use and e-participation.

The Web Index is based to a large extend (60%) on specifically collected primary data using surveys amongst local experts. The limitations and statistical issues of this approach are discussed in Annoni & Nardo (2012) who conclude that the index is a robust one but some questions need to be refined and some indicators are redundant. Unfortunately, Luxembourg is not (yet) included in the list of countries covered.

**3.6.2_ The Netindex**

Based on widely used speed testing tools[34], Ookla[35] calculates the so-called Netindex[36] which is freely available and constantly updated. It defines 5 different indices for upload, download, quality, promise and value and presents OECD, G8, APAC and EU averages as well as an individual country measurement and rank updated daily. This is a good example of how the development of the internet itself provides the tools to measure and assess its performance and more of such tools are likely to appear in the future.

**3.6.3_ The Akamai - State of the internet report**

Akamai[37] has set up a global content delivery network that replicates content of major internet sites in order to improve and speed-up access this content. Using

29_This list does not claim to be complete but focusses on the mäin indicators which are available for Luxembourg

30_http://www.nokiasiemensnetworks.com/ accessed on 13.7.2013

31_www.cisco.com accessed 13.7.2013

32_http://www.booz.com/uk/home accessed 13.7.2013

33_ http://thewebindex.org/ accessed 13.7.2013

34_http://www.speeedtest.net/ accessed 13.7.2013 and http://www.pingtest.net/ accessed 13.7.2013

35_https://www.ookla.com/ accessed 13.7.2013

36_http://www.netindex.com/about/ accessed 13.7.2013

37_http://www.akamai.com accessed 10.8.2013 this network, they do produce a quarterly "state of the internet" report including connection speeds, attack traffic, network connectivity, availability and latency problems, IPv6 transition as well as traffic patterns of leading web sites and digital content providers.

In its recent edition (Akamai, 2013), the report covers 177 countries including Luxembourg but it should be noted the due to a limited number of customers in Luxembourg, the results may not be representative and are not commented about by Akamai.

### 3.7_ Assessments of Telecommunications Regulations

In addition to ICT infrastructures, usage and skills, it can be interesting to identify how successful a country has been in "liberalising" its telecommunications markets. In that respect, some researchers have come up with assessment of the strengths of the respective national regulatory agencies.

#### 3.7.1_ Polynomics regulation index

In order to study the effect to sector-specific regulations, Polynomics[38] proposes an index to measure the "density" of regulation (Polynomics, 2012a, 2012b; Zenhaeusern & Schneider, 2012; Zenhaeusern, 2012). It is based on coded answers to about 30 questions regarding telecommunications regulations. All questions were selected to relate to investment and innovation activity by telecommunications companies.

They either concern fixed, mobile or next generation access networks or multiple of these. This gives a total of about 40 indicators per country and per year. The indicators have so far been collected for all of the EU countries for period between 1997 and 2010 and give a good overview about how regulation processes have evolved over time.

#### 3.7.2_ Telecommunications Governance Index

Waverman & Koutroumpis (2011) designed an index of the effectiveness of the institutional design of telecommunications regulators for 142 countries called "Telecommunications Governance Index" (TRGI) and compared this index to the transparency of the general political governance in the respective countries.

The index is made up of 5 equally weighted components: regulatory transparency, independence, resource availability, enforcement on licensees and per capita income.

All components except the GDP/capita are derived from ITU information about regulators either directly or using relevant proxies. The countries were plotted on a two-by-two matrix using TRGI and Political transparency as axis and grouped into 4 categories and analysed on a regional basis.

### 3.8_ Different purposes and objectives

As shown in the (necessarily incomplete) picture above, there is a wide range of indices and frameworks available. It is important to keep in mind the different and sometimes conflicting purposes and objectives of these different models as these will have influenced the number and choice of sub-indices, their respective weightings and statistical treatment and, therefore their overall relevance for the task at hand.

The summary table below provides an overview of the frameworks that will be used in section 6 for collecting information about Luxembourg, identifying their scope, their objectives and commenting on their underlying data and methodology.

## 4_ Luxembourg's ICT development from different viewpoints

The following section will present empirical evidence extracted from the different sources identified above. The intention is to present a broad coverage of the different aspects of ICT readiness, usage and impact. Due to space limitation, the chosen subset will necessarily be subjective but, by using different sources[39], the authors have tried to identify the major strengths and weaknesses of Luxembourg's current state of ICT development.

| Organisation | Scope | Objectives | Comments |
|---|---|---|---|
| Service des Médias et de la Communication | National | Present Luxembourg to the "outside" world | Marketing oriented – only the positive aspects shown |
| Institut Luxembourgeois de Régulation | National | Assessment of the telecommunications market | Limited to figures about telecommunications market |
| STATEC | National | Establish the extent of ICT access and usage | Focus on equipment in households and enterprises |
| Eurostat | European Union | Compare EU members states in terms of ICT usage and access | Based on statistical information from Members |
| Digital Agenda Scoreboard | European Union | Measure progress on i2020 agenda | High political visibility |
| Digital Divide | European Union | Identify differences within EU between "old" and "new" members | Does not take into account gender, regions, skills…. |
| World Economic Forum - Networked Readiness Index | 144 countries in 2013 | Global country rankings, advise to policy makers and managers | Varying set of indicators and countries, mixed qualitative and quantitative approach, methodology not completely transparent |
| International telecommunications Union - Price Basked | Global | Establish pricing level of standardized basket of ICT services | Not collected every year, information may be outdated |
| International telecommunications Union - Development Index | Global | Establishing development of ICTs on a global scale, measuring the digital divide | Variable underlying data quality, not published annually, information may be outdated |
| OECD Communications Outlook | Global | State of communications infrastructure and prices | Some information from earlier data collections |
| OECD Internet Economy Outlook | Global | Focus on use of the internet | Inconsistencies in inputs from countries |
| World Bank Knowledge Economy | 146 countries | Focus on education, knowledge and skills | ICT as important underlying driver, limited time series available |
| CISCO Broadband Quality Score | Varied subset of countries | Broadband infrastructure only | Only available for 2008,2009 and 2010 |
| Booz&Co Digitization Index | 150 countries | Alternative country ranking focussing on infrastructures | Initial set only available for a limited set of countries, not updated on a regular basis |
| Webindex | 61 countries | Limited to internet infrastructure and usage | Independent local experts provide underlying information (not yet available for Luxembourg) |
| Netindex | Internet | Direct collection of live traffic information | Changes almost on a daily basis, not clear what the underlying methodology is |
| Akamai State of the Internet | 177 countries but limited to Akamai customers | Aggregated information collected within their content delivery network | Methodology not clear, limited number of customer sites |
| Polynomics Regulation Index | EU members, some OECD | For traditional and NGN networks | Based on qualitative interviews |
| Telecommunications Governance index | 142 countries | Based country data from ITU | Derived from multivariate statistical analysis |

_Table 1: Summary of different frameworks used in section 6 below

### 4.1_ Local Luxembourg evaluations

#### 4.1.1_ Market overview according to the National Regulatory Authority

This section presents a general overview of the telecommunications market in Luxembourg in 2012 according to the National Regulatory Authority (ILR, 2013). For more information about the historical evolution of the market and a complete list of market participations see (Binsfeld, Whalley, & Pugalis, 2013) and (ILR, 2004a, 2004b, 2013, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012).

##### 4.1.1.1_ Market size in 2012 and investments

Total turnover was 513.3 million Euro with was almost identical for 2011 (+0.38%). Fixed services continued to decline by 5.77% to 227.1 million Euro. Mobile network services increased by 5.8% to 286.2 million Euro. In addition, CATV Networks generated about 34.8 million Euro. In absolute terms, this is a very small market in line with the small size of the country, but on a per capita basis OECD (OECD, 2013) ranks Luxembourg, with about 1400 USD/

38_http://www.polynomics.ch/en/welcome.php accessed 13.7.2013

39_Which may however rely very often on the same underlying data sets

| | Number | Net floor space ft² | Net floor space m² | Data centre operators | Data centre service providers |
|---|---|---|---|---|---|
| Tier I | 0 | - | - | - | - |
| Tier II | 5 | 26 910 | 2 500 | Cegecom-Artelis, eBRC, SES, Sungard, Visual Online | Cegecom-Artelis, eBRC, SES, Sungard, Visual Online |
| Tier III | 7 | 90 955 | 8 450 | BCE, BT, Cetrel, eBRC, LAB data Vault PSF, SecureIT, Verizon | BCE, BT, Cetrel, eBRC, LAB data Vault PSF, SecureIT, Verizon, colocated: Datacenter Luxembourg |
| Tier IV | 6 | 267 064 | 24 811 | eBRC, EDH (European Data Hub) run by CSC, LuxConnect | eBRC, EDH (European Data Hub) run by CSC, LuxConnect, colocated: Cegecom-Artelis, Conostix, Datacenter Luxembourg, IBM, Iris, Netcore, Orange Business Services, SecureIT, Solido, Steria PSF Luxembourg, Systemat, Telecom Luxembourg Private Operator, Telindus Telecom, Visual Online |
| Multi-tier | 1 | 51 128 | 4 750 | LuxConnect | LuxConnect, colocated: Datacenter Luxembourg, IBM, Root, Systemat, Tech-IT PSF, Telecom Luxembourg Private Operator, Telindus Telecom |
| Total | 19 | 436 057 | 40 511 | | |

_Table 2: Data centres in Luxembourg (source: Luxembourg for Business)

Capita spend in telecommunications, 4th largest behind Switzerland, Australia and the United States.

Total fixed and mobile network investments grew substantially to 133.3 million Euro, the largest part 112.4 million Euro (+26.6%) in fixed networks. This is largely due (91.1%) to the deployment of the country's fibre to the home network (SMC, 2010) by the incumbent operator "Entreprise des Postes et Télécommunications" (EPT)[40], The 3 mobile networks[41] operators invested 20.98 million Euro (-18.3%) mainly in 4G LTE deployments. Thus a very high 25.9 % of the total turnover were invested and this ratio increased compared to previous years.

### 4.1.1.2_ Mobile networks

Mobile subscriptions (excluding pure data cards and machine to machine only (25100)) reached 762.000 (compared to a population of 520.000). Outgoing voice minutes grew by 8.13 % to 993.37 million, 982.3 million SMS were sent (+6.04%) and mobile data volume grew to 4673 TBytes, an increase of 149% compared to 2011. Mobile internet users also grew from 299300 in 2011 to 385100 in 2012. Apparently, customers are willing to use the full potential of their smartphones even though this generates higher costs and thus the average monthly revenue per user grew to 31.3 Euro.

### 4.1.1.3_ Fixed voice and leased lines

Subscriptions decreased from 280000 to 269000 and this confirmed a long-term trend. A large part of those being residential customers (66.7%). However, about 60% of the revenues in fixed voice services are generated by business users (voice and leased lines)

### 4.1.1.4_ Next Generation Access

Voice over Broadband services grew substantially to 31500 subscribers. Internet (broadband and ultra-high broadband) grew to 169000 (+4.26%). Ultra-High broadband (downstream higher than 30 Mbit/s). In total some 27000 households are now using either "fibre to the node", "fibre to the home" or "DOCSIS3.0[42] Cable TV" next generation broadband access. This represents an increase of 146.36% compared to 2011.

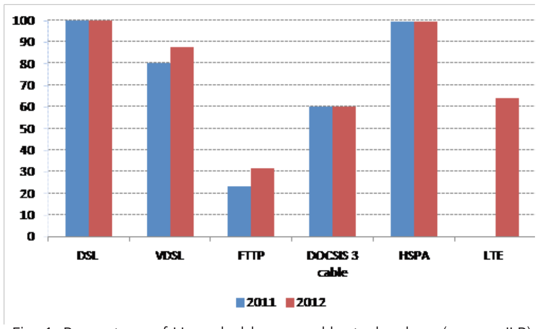


_Fig. 1: Percentage of Households covered by technology (source: ILR)

Broadband internet access is available in some form all over Luxembourg (see figure 1 above), fibre connectivity reaches about 32% of population and is growing rapidly. Cable TV subscriptions are decreasing due to a fierce competition from different IP-TV services[43], but internet over cable subscriptions have increased to 30.000 (+36.4%). Service bundles (triple and quadruple play) are becoming increasingly popular with a total of 223000 subscribers. Triple play (mobile and fixed voice plus internet access) grew by 36.6% to 112000 subscribers.

### 4.1.2_ Service des Médias et des Communications

As mentioned above, the Minister of Communications and together with the Ministry of Economy and Foreign Trade published a reference document "Luxembourg & ICT – a snapshot". This is largely based on information from

40_http://www.post.lu/fr/ and www.pt.lu accessed 14.7.2013

41_www.luxgsm.lu, www.tango.lu, www.orange.lu accessed 14.7.2013

42_http://www.cablelabs.com/cablemodem/ accessed 14.7.2013

43_http://www.tele.lu/ger, http://www.tangogeneration.lu/notre-tv/nos-offres, http://www.internet.lu/loltv_home.htm accessed 10.8.2013 secondary sources and presents Luxembourg according to its ICT development but also to several additional indices which are outside of the scope of this document. However, it also contains some original information mainly about Luxembourg's international connectivity and the underlying national and international carriers as well as round-trip times to the major European peering points. It argues that the central geographic location of Luxembourg makes it not just easy to access physically but also positions it well for on-line applications which need quick response e.g. gaming services.

There is also some information about datacentre capacity and quality (see table 3 below). There are different datacentres available in Luxembourg representing about 20% of the world's total high availability[44] datacentre capacity.
Overall, this document concludes that the ICT infrastructures are well developed in Luxembourg, that access and usage of ICT reaches almost 100% and the Government sees ICT as one of its "strategic" priorities for the development of the local economy.

### 4.1.3_ STATEC

Statec provides information on the usage of ICT by businesses and house-holds including time-series for some major indicators.

It can been seen that most business are using some form of IT but that collaborative tools other than emails are not widely used so far. Local area networks are present in all enterprises but Wireless Lan is only used in less than half of them. Indeed many of the financial institutions are still expressing security concerns when it comes to wireless access.

Almost all enterprises have some form of internet access and most of these broadband access. However, ISDN modems

| Year | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|
| Entreprises using IT | 97,5 | 98,1 | 97,3 | 97,9 | 97,3 | 98,0 | 98,4 | 98,4 |
| Technologies used | | | | | | | | |
| Intranet | 45,7 | 44,8 | 45,0 | 54,7 | 41,0 | 35,2 | 48,7 | 48,5 |
| Shared calendar | ... | 29,0 | 27,8 | 34,8 | 36,0 | 36,9 | 38,2 | 39,3 |
| Extranet | 27,5 | 25,0 | 25,8 | 28,7 | 34,0 | 33,9 | 35,4 | 32,3 |
| Open Source | - | - | 12,6 | 15,7 | 17,3 | 18,1 | 29,8 | ... |
| Project Management | ... | 12,5 | 13,4 | 16,6 | 16,0 | 18,9 | 19,3 | 19,5 |
| Videoconferencing | ... | 5,7 | 6,8 | 10,1 | 9,2 | 11,4 | 13,8 | 16,3 |
| Electronic Forums | ... | 7,4 | 8,4 | 12,0 | 12,8 | 14,5 | 13,4 | 15,3 |
| Email | ... | 87,8 | 92,3 | 88,4 | 87,3 | ... | ... | ... |
| Local Area Network | 93,4 | 96,8 | 98,1 | 98,7 | 98,8 | 100,0 | ... | ... |
| Wireless Lan | 15,3 | 22,9 | 27,2 | 35,3 | 41,5 | 42,9 | ... | ... |

_Table 3: ICT usage in Businesses over time (source: Statec)

| Year | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|
| Business with Internet | 95 | 95 | 97 | 98 | 98 | 98 | 98 | 99 |
| Broadband connectivity | 70 | 81 | 86 | 91 | 91 | 90 | 95 | 97 |
| DSL (xDSL, ADSL, SDSL, etc.) | ... | 74 | 80 | 85 | 86 | 86 | 87 | 89 |
| CableTV, Leased lines | ... | 16 | 16 | 19 | 20 | 18 | 28 | 34 |
| ISDN Modem | 50 | 49 | 40 | 34 | 33 | 29 | 26 | 30 |
| Mobile | ... | 19 | 22 | 34 | 40 | 48 | 54 | 53 |
| 3G Mobile | ... | ... | ... | ... | ... | 21 | 28 | 41 |
| Other mobile (WLAN) | ... | ... | ... | ... | ... | 44 | 49 | 40 |
| Banking and Financial Services | 75 | 76 | 79 | 79 | 83 | 85 | ... | ... |
| Online Training | 13 | 15 | 21 | 23 | 25 | 24 | ... | ... |
| E-Government | ... | ... | ... | 94 | 91 | 94 | 91 | 91 |
| Web based forms | ... | 84 | 86 | 90 | 88 | 90 | 89 | 86 |
| Infrormation | ... | 77 | 80 | 85 | 86 | 88 | 86 | 84 |
| Completed froms retrieval | ... | 35 | 38 | 43 | 43 | 50 | 59 | 63 |
| Adminstrative procedures | ... | ... | ... | 29 | 30 | 39 | 40 | 49 |
| Request for proposals | ... | ... | 5 | 7 | 13 | 15 | 10 | 11 |

_Table 4: Web Access and Usage by Enterprises (source: Statec)

| Année | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|
| Businesses with a web site | 64 | 65 | 66 | 67 | 71 | 73 | 77 | 78 |
| Price lists or catalogues | 39 | 41 | 39 | 50 | 50 | 50 | 42 | 40 |
| Job Offering | ... | ... | ... | 32 | 35 | 33 | 37 | 38 |
| On-line ordering | ... | ... | ... | 21 | 19 | 20 | 21 | 22 |
| Trust certifications | ... | ... | ... | ... | 12 | 18 | 19 | 22 |
| Personalised content | ... | ... | ... | 12 | 11 | 13 | 11 | 12 |
| On-line delivery tracking | ... | ... | ... | ... | 8 | 10 | 10 | 11 |
| Product personalisation | ... | ... | ... | 17 | 11 | 12 | 9 | 9 |
| Online ordering (at least 1% of orders) | 22 | 30 | 34 | 35 | 34 | 35 | 33 | 36 |
| Online sales (at least 1% of sales) | 10 | 11 | 13 | 12 | 10 | 15 | 15 | 17 |

_Table 5: Web presence and E-commerce (source: Statec)

| Year | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|
| HH with PC | 74,5 | 77,1 | 80,0 | 82,8 | 87,9 | 90,0 | 91,7 | 92,0 |
| HH with Internet Access | 64,6 | 70,2 | 74,6 | 80,1 | 87,2 | 90,0 | 91,0 | 93,0 |
| Broadband (DSL, Fibre, CATV) | 51,7 | 62,8 | 77,5 | 76,2 | 81,5 | 78,0 | 75,0 | 73,0 |
| Analogue/ISDN dial-up | 51,0 | 36,3 | 25,7 | 24,1 | 19,5 | 30,0 | 27,0 | 22,0 |
| DSL line | 49,0 | 59,4 | 75,8 | 73,9 | 79,4 | 70,0 | 63,0 | 61,0 |

_Table 6: Households with a PC and Internet (source: Statec)

44_Tier IV according to http://uptimeinstitute.com/ accessed 14.7.2013 are also still use and mobile access specially over 3G and WLAN networks for smartphones and tablets is getting increasingly popular. Many organisations use the internet for banking and other financial transactions, most do also some government interactions and transactions over the web.

In terms of E-commerce, 78% of enterprises do operate a web site but these are not widely used for e-commerce transactions so far. E-commerce appears to be done more on an international than a local scale.

On the residential side, over 90% of households to own a personal computer and have access to the internet. Over 70% also have a broadband connection (mainly some form of xDSL or cable), both percentages have increased substantially since 2005.

Overall, these indicators confirm that Luxembourg's population and entreprises have access to ICT and are using it widely.

### 4.2_ Luxembourg within the European Union

#### 4.2.1_ Eurostat

Eurostat uses the statistics provided by Statec and compares Luxembourg with other EU member states. They also look more deeply into the actual usage characteristics and the level and skills of IT professionals. The following presents an extract of the wealth of information available based on Digital Agenda Scoreboard indicators.

In terms of actual internet usage Luxembourg scores amongst the top 3 performers in the EU with about 90% of households using the internet regularly. Only 6% never use the internet.

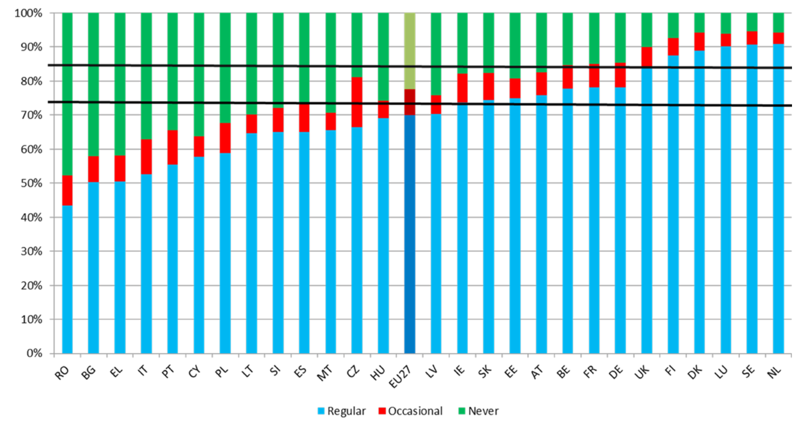


_Fig. 2: Internet usage (source: Eurostat)

About 40% of the working population claim to have reached a high level of computer skills and although this might be a very subjective assessment, it is substantially higher than the EU average. On the other hand, the amount of people admitting to have low IT skills is below the EU average. Obviously both indicators might be very subjective and therefore unreliable.

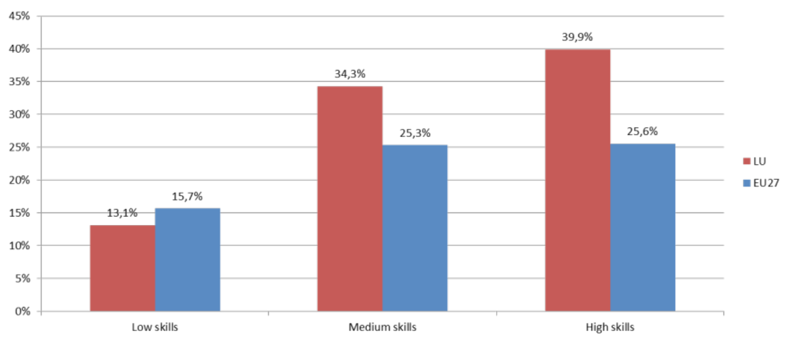


_Fig. 3: Levels of computer skills

In terms of ICT professionals Luxembourg is amongst the top 10 countries in the EU with about 4.8% of the working population active in ICT. It should however be considered that a large part of the working population comes from outside of Luxembourg (Schmitz, Drevon, & Gerber, 2012), (Service des Médias et des Communications, 2013) so that this figure needs to be treated with care.

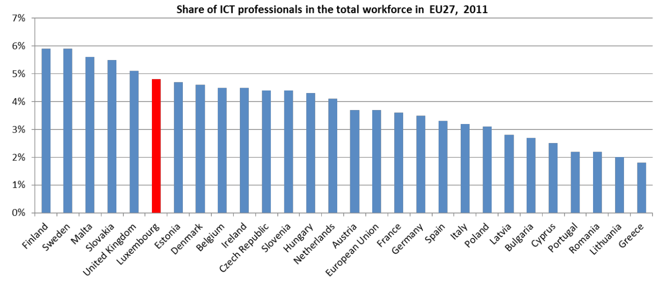


_Fig. 4: ICT Professionals

This seems to be confirmed with by the fact that Luxembourg is one of the countries that has most difficulties to recruit suitable ICT specialists and filling vacancies in this area as shown in the figure below.

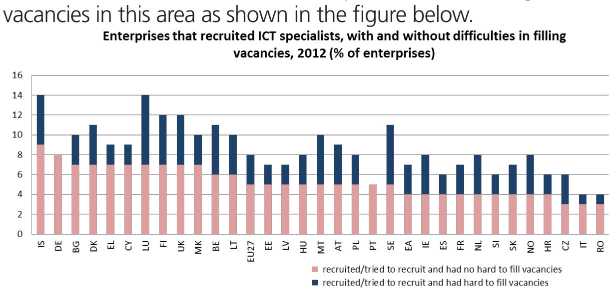


_Fig. 5: Difficulties in recruiting ICT professionals

In terms of E-commerce it appears that most of it is done on a cross-border relationship with e-commerce providers like Amazon, Ebay and Itunes being very popular. This is not surprising given the small size of the country and the fact that local enterprises are not providing much e-commerce offerings so far (see table 5 above). In terms of Small and Medium size Enterprises (SME) selling online, Luxembourg reaches the EU average of about 14%.

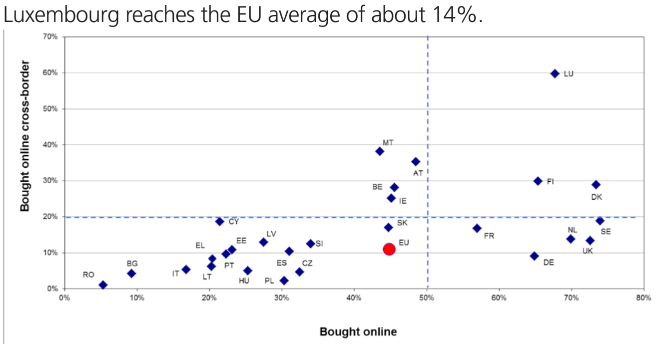


_Fig. 6: Citizens engaging in Ecommerce

In terms of E-government, a lot of efforts have been carried out recently and Luxembourg positions itself amongst the top 10 countries in the EU.

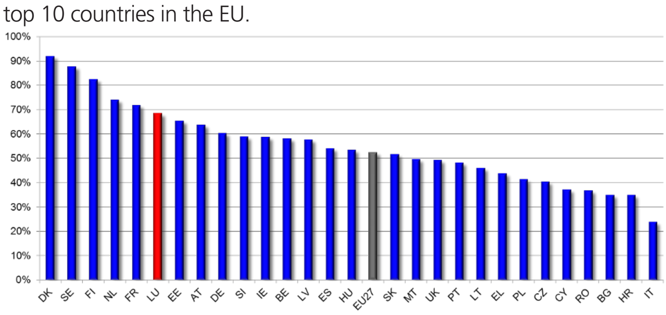


_Fig. 7: Electronic interaction by citizens with public authorities

However, on the use of ICT by public authorities themselves, whilst at a relatively high level, Luxembourg is outperformed by many EU members and even some of the new member states from Central Europe.

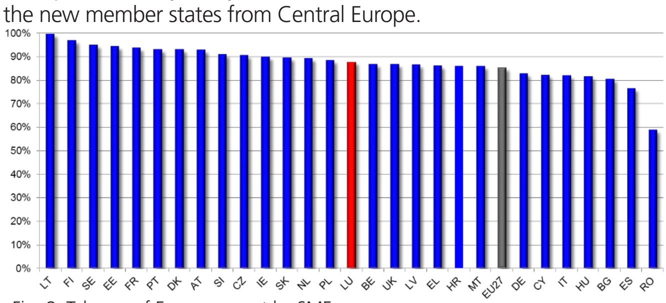


_Fig. 8: Take-up of E-government by SMEs

Overall, according to Eurostat, the share of gross value added by the ICT sector in Luxembourg is considerably more important than the EU average (second behind Ireland). This is not surprising as the local economy is to a large extend "services oriented" and dominated by the financial sector which needs a lot of ICT infrastructures and services as an underlying platform to offer their own products and services. It should be noted that there is nearly no ICT manufacturing[45] in Luxembourg so that the bulk of the value added comes from ICT services.

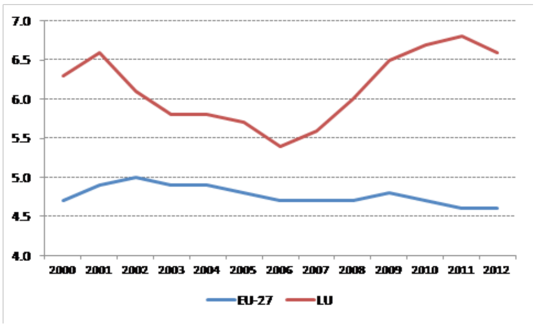


_Fig. 9: Share of Gross Value Added (%, at basic prices)

### 4.2.2_ Digital Agenda scoreboard

As part of the Digital Agenda for Europe scoreboard (DAE), the European Commission assesses the main telecommunications market and regulatory developments in the member states. The most recent report is not yet available but in 2011, Luxembourg was considered to be committed and well on track to make it "the first fully fibred country in Europe" (European Commission, 2012b).

This was confirmed by a special report on broadband availability in Europe (European Commission, 2013a) and in the latest DAE report (European Commission, 2013b). In the following, the authors present a comparison of Luxembourg in the main DAE indicators related to ICT infrastructure and access.

In terms of standard fixed broadband access defined as xDSL, Cable, FTTP and WiMAX[46], Luxembourg scores amongst the top 5 countries with an almost 100% availability.

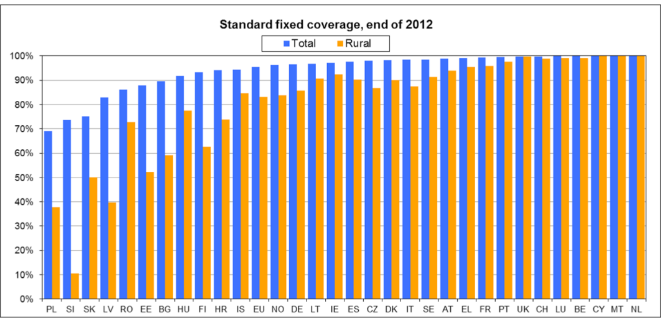


_Fig. 10: Fixed broadband availability (source: Point Topic)

The same applies for the so-called Next Generation Access (NGA) ie ultra-high broadband access including VDSL, Cable DOCSIS3.0, FTTH. The EU average is at about 54% of Households and Luxembourg is much higher amongst the top 5 countries of the EU and Switzerland. This confirms that the substantial investments made in FTTH infrastructure shown above are showing good results.

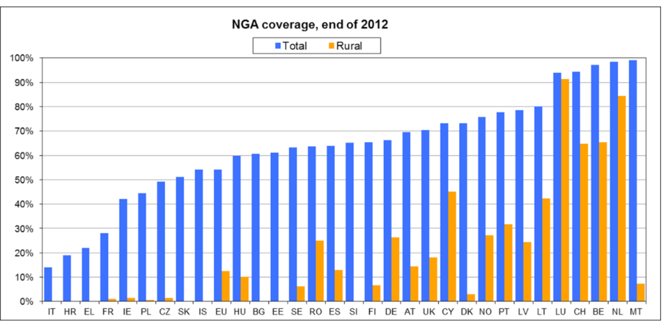


_Fig. 11: Next Generation Access (source: Point Topic)

However, take up and usage of NGA is a different story and by far the largest part of population still uses "standard broadband".

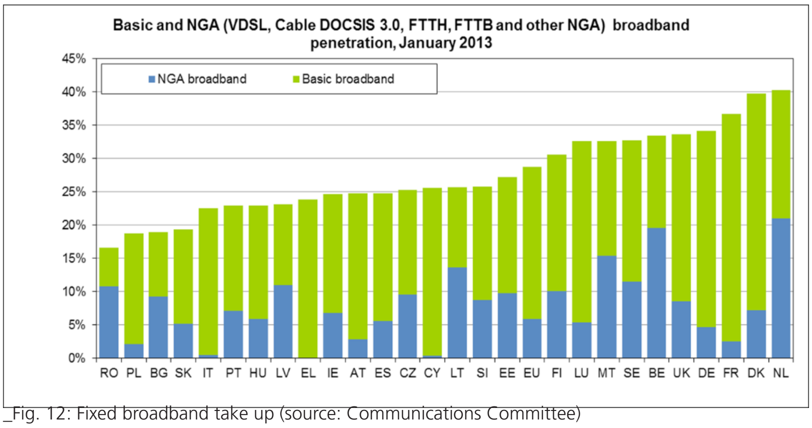


_Fig. 12: Fixed broadband take up (source: Communications Committee)

Luxembourg appears also to lack behind about 15 EU member states and EU average with only 17% of of households actually using either FTTH, VDSL or DOCSIS3.0 cable.

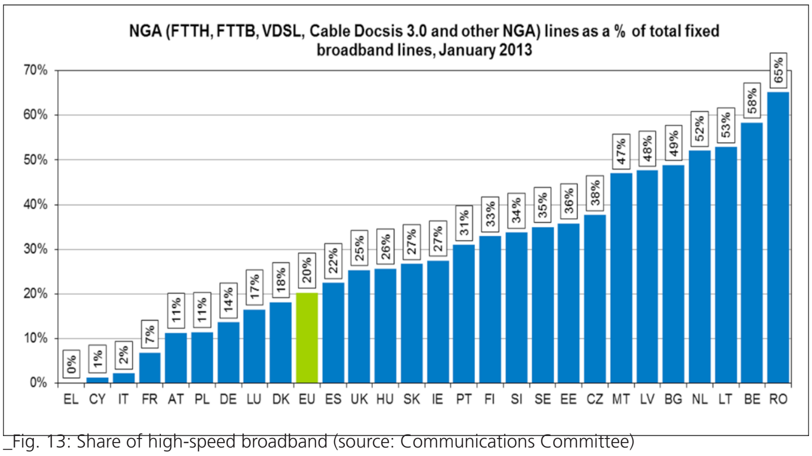


_Fig. 13: Share of high-speed broadband (source: Communications Committee)

Similarly in terms of the bandwidth actually offered, about 80% is below 30 Mbit/s. One possible explanation for this may be the dominance of the incumbent operator who has no interest to "cannibalise" its xDSL business and most importantly its leased line business for business customers.

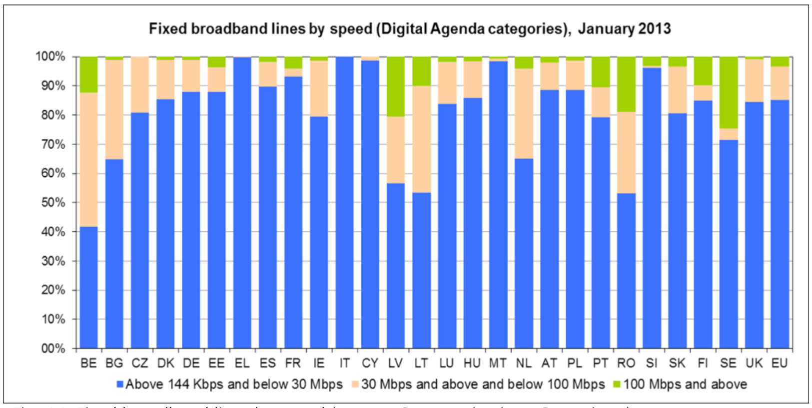


_Fig. 14: Fixed broadband lines by speed (source: Communications Committee)

From the assessments above it can be seen that the telecommunications infrastructure in Luxembourg is well developed and continues to be extended and upgraded. On the supply side, Luxembourg has a good chance to become the first "fully fibred" country in the EU, however on the demand side, take up of the new technologies is lagging behind.

### 4.2.3_ The digital divide within the EU

This study was carried out for 2008, 2009 and 2010 (Cruz-Jesus et al., 2012) and Luxembourg was classified for all 3 years of study into the "digital leaders" cluster together with Denmark, Finland, Sweden and the Netherlands. There appears to be an improvement over the years in terms for the "ICT infrastructure and adoption by population" dimension

45_According to OECD definition

46_A WiMAX licence has been awarded in Luxembourg but there are no services offered which is visible for many of the EU member states. On the "e-business and internet access cost dimension however – no real improvement is visible, the situation is more or less identical during the 3 years and Luxembourg, together with Finland scores less well than Denmark, Sweden and the Netherlands.

As an aside, the "digital laggards" are all coming from the new member states in CE and this suggests that there is indeed a "digital divide" apparent within the EU.

### 4.3_ International organisations

#### 4.3.1_ World Economic Forum's "Networked Readiness Index"

The section below presents an analysis of the Networked Readiness Index (NRI) and its evolution over time for Luxembourg. It also presents an analysis of the major strengths (sub-indicators Luxembourg performed well) and weaknesses (sub-indicators it does not perform well). As mentioned above, the time series analysis needs to be treated with care as the methodology, the number of countries and the split between quantitative and qualitative measures has considerably evolved over time.

Table 8 and the figure 15 below show the actual value of the NRI and for the sub-indexes environment, readiness, usage and (since 2012) impact, as well as the rankings in the different categories. A percentage change has been calculated between 2003 and 2013 (intermediate values were difficult as even the scaling changed over time).

It can be concluded that on most indicators as well as on the so-called pillars, Luxembourg has improved over time and on some occasions even substantially. There are only 3 pillars for which this not the case: infrastructure environment (although this was dropped in 2011) which is surprising as a lot of the Government initiatives went into the development of the infrastructure, business readiness and skills. On "affordability" it almost stayed constant since 2003.

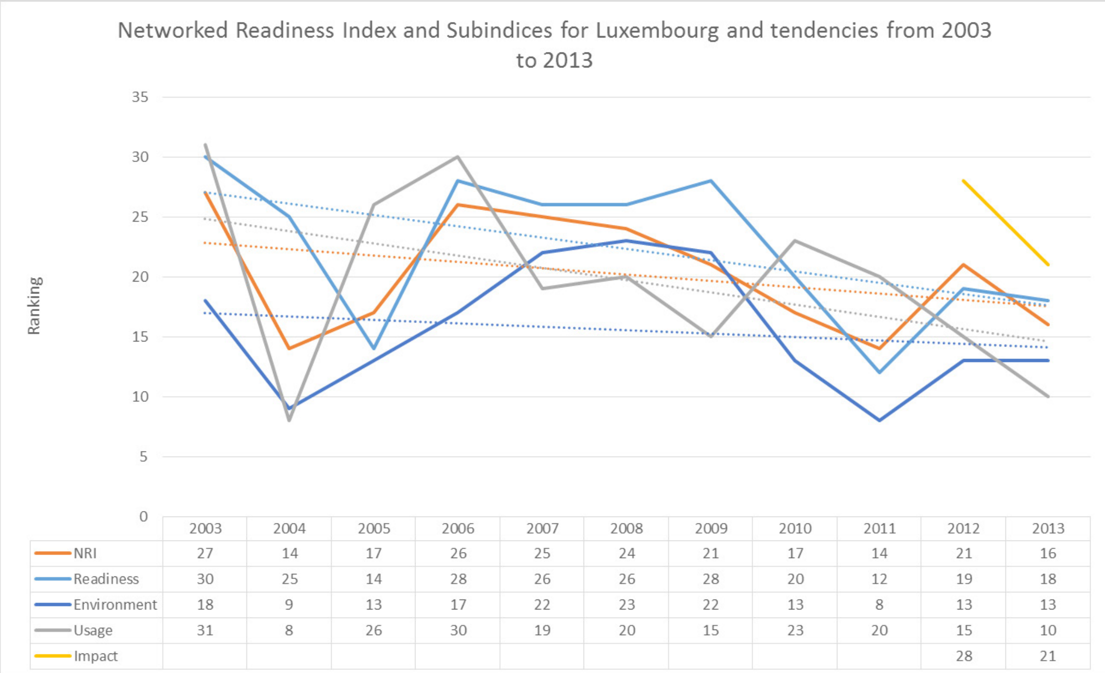


_Fig. 15: Evolution of NRI for Luxembourg (source: World Economic Forum)

| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | % change 2003-2013 (or latest year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **NRI** | **4,55** | **4,76** | **1,04** | **0,8** | **4,9** | **4,94** | **5,1** | **5,02** | **5,14** | **5,22** | **5,37** | **18%** |
| Rank | 27 | 14 | 17 | 26 | 25 | 24 | 21 | 17 | 14 | 21 | 16 | |
| ***Environment*** | **4,81** | **4,64** | **1,44** | **1,24** | **4,62** | **4,67** | **4,82** | **5,33** | **5,5** | **5,27** | **5,25** | 9% |
| Rank | 18 | 9 | 13 | 17 | 22 | 23 | 22 | 13 | 8 | 13 | 13 | |
| Market Environment | 3,79 | 4,27 | 1,14 | 0,86 | 4,46 | 4,86 | 5,02 | 5,4 | 5,41 | | | 43% |
| Rank | 33 | 8 | 19 | 22 | 24 | 20 | 16 | 4 | 3 | | | |
| Political and regulatory environment | 5,03 | 5,17 | 1,4 | 1,19 | 5,31 | 5,44 | 5,39 | 5,99 | 6,06 | 5,79 | 5,77 | 15% |
| Rank | 15 | 10 | 13 | 22 | 22 | 18 | 13 | 4 | 5 | 5 | 4 | |
| Infrastructure environment | 5,59 | 4,48 | 1,78 | 1,67 | 4,1 | 3,71 | 3,84 | 4,59 | 5,02 | | | -10% |
| Rank | 3 | 18 | 10 | 12 | 22 | 35 | 29 | 19 | 18 | | | |
| Business and Innovation environment | | | | | | | | | | 4,75 | 4,73 | 0% |
| Rank | | | | | | | | | | 27 | 34 | |
| ***Readiness*** | **4,93** | **4,96** | **0,94** | **0,51** | **5,05** | **5,29** | **5,26** | **5,09** | **5,17** | **5,86** | **5,79** | **17%** |
| Rank | 30 | 25 | 14 | 28 | 26 | 26 | 28 | 20 | 12 | 19 | 18 | |
| Individual readiness | 5,07 | 5,04 | 0,85 | 0,83 | 6,05 | 6,07 | 5,95 | 5,22 | 5,44 | | | 7% |
| Rank | 32 | 28 | 20 | 24 | 18 | 24 | 27 | 25 | 22 | | | |
| Business readiness | 5,12 | 5,19 | 0,54 | 0,29 | 4,82 | 4,79 | 4,78 | 4,82 | 4,76 | | | -7% |
| Rank | 22 | 25 | 27 | 35 | 29 | 38 | 39 | 30 | 22 | | | |
| Goverment readiness | 4,61 | 4,65 | 1,44 | 0,42 | 4,29 | 5,01 | 5,05 | 5,23 | 5,32 | | | 15% |
| Rank | 28 | 28 | 7 | 33 | 32 | 21 | 18 | 10 | 7 | | | |
| Infrastructure and digital content | | | | | | | | | | 6,17 | 6,43 | **4%** |
| Rank | | | | | | | | | | 13 | 12 | |
| Affordability | | | | | | | | | | 5,74 | 5,61 | -2% |
| Rank | | | | | | | | | | 36 | 48 | |
| Skills | | | | | | | | | | 5,66 | 5,33 | -6% |
| Rank | | | | | | | | | | 31 | 33 | |
| ***Usage*** | **3,9** | **4,67** | **0,75** | **0,66** | **5,02** | **4,87** | **5,21** | **4,65** | **4,74** | **5,26** | **5,62** | 44% |
| Rank | 31 | 8 | 26 | 30 | 19 | 20 | 15 | 23 | 20 | 15 | 10 | |
| Individual usage | 4,57 | 6 | 1,36 | 1,66 | 4,93 | 4,72 | 5,69 | 5,82 | 6,05 | 5,91 | 6,47 | **42%** |
| Rank | 8 | 1 | 13 | 13 | 9 | 9 | 4 | 5 | 3 | 7 | 4 | |
| Business usage | 3,56 | 4,62 | 0,8 | 0,74 | 5,38 | 5,18 | 5,29 | 3,94 | 4,16 | 5,03 | 4,97 | 40% |
| Rank | 49 | 19 | 25 | 30 | 26 | 27 | 23 | 28 | 18 | 18 | 16 | |
| Government usage | 3,56 | 3,4 | 0,09 | -0,42 | 4,76 | 4,7 | 4,64 | 4,19 | 4 | 4,83 | 5,41 | 52% |
| Rank | 52 | 43 | 48 | 73 | 31 | 25 | 27 | 41 | 42 | 20 | 13 | |
| ***Impact*** | | | | | | | | | | **4,5** | **4,81** | 7% |
| Rank | | | | | | | | | | 28 | 21 | |
| Economic impacts | | | | | | | | | | 4,07 | 4,47 | 10% |
| Rank | | | | | | | | | | 30 | 25 | |
| Social impacts | | | | | | | | | | 4,96 | 5,15 | 4% |
| Rank | | | | | | | | | | 34 | 20 | |

_Table 7: Networked Readiness changes (source: World Economic Forum)

Luxembourg, although improving in absolute terms, lost pace compared to its "competitors". It would appear that the efforts made by politicians and regulators have been able to compensate this and have put Luxembourg amongst the top 20 countries in the World. It is interesting to note as well that Luxembourg's position worsened in 2011 when the methodology was changed.

Looking into the details in the 2013 report, Luxembourg's main strengths seem to be related to its small size and its flexibility to adapt to market changes e.g. in terms of laws related to ICT, number of procedures, effectiveness of law making bodies and the fact that most households and businesses are using computers and the internet. The government's willingness and vision to develop ICT is also seen as a strength.

above, the country ranks extremely poor in terms of skills and this ranking has even worsened since 2002[47] which overall leads to a substantial reduction of the general IDI score and ranking.

### 4.3.3_ OECD Communications and Internet Economy Outlook

This section provides a summary of the main strengths and weaknesses of Luxembourg according to the latest OECD Communications (OECD, 2013) and Internet Economy Outlook (OECD, 2012b) reports.

OECD has defined a set of 15 key indicators[48], some of which, however, are not available for Luxembourg e.g. top 250 ICT firms, R&D in ICT because of the small size of the market and the fact that there is practically no ICT manufacturing in Luxembourg. Therefore, the authors have identified in the two publications mentioned above, all of the indicators which include Luxembourg and its respective ranking.

| Strengths | Rank | Weaknesses | Rank |
|---|---|---|---|
| Laws relating to ICT | 1 | Tertiary education gross enrolment rate % | 112 |
| Internet & telephony competition | 1 | No. Days to start a business | 81 |
| Software piracy rate % software installed | 2 | Fixed broadband internet tariffs PPP USD/month | 64 |
| Households with Personal computer (%) | 3 | Quality of management schools | 60 |
| Impact of ICTs on access to basic services | 3 | Mobile cellular tariffs, PPP USD/min | 59 |
| Effectiveness of law making bodies | 4 | Intensity of location competition | 58 |
| Extent of staff training | 4 | No. Procedures to start a business | 48 |
| No. Procedures to enforce a contract | 5 | Quality of math&science education | 46 |
| Indivuduals using Internet (%) | 5 | E-Participation | 38 |
| Importance of ICT to government vision | 5 | Quality of educational system | 36 |

_Table 8: Strengths and weaknesses according to NRI (source: World Economic Forum)

Several of the weaknesses appear to be linked to education in terms of tertiary education, management schools, math&science education and the overall quality of the educational system – all not directly related to ICT. Some of the tariffs which seem to be still relatively high and there appears to be a relatively low intensity of competition.

| Price basket | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|
| GNI/capita USD | 75880 | 84890 | 76710 | 77160 |
| IPB | 0,4 | 0,47 | 0,5 | 0,5 |
| Rank | 3 | 5 | 7 | 5 |
| Fixed PB | 0,5 | 0,42 | 0,4 | 0,4 |
| Rank | 11 | 15 | 14 | 13 |
| Mobile PB | 0,2 | 0,18 | 0,4 | 0,4 |
| Rank | 7 | 7 | 13 | 12 |
| Broadband PB | 0,7 | 0,59 | 0,6 | 0,6 |
| Rank | 5 | 7 | 7 | 6 |

_Table 9: ITU Price Basket (source: ITU)

In terms of IPB, Luxembourg ranks amongst the top 10 countries in the world, which is not surprising given the country's very high Gross National Income per Capita. However, no major changes can be seen over time, except for mobile communications which appear to have become more expensive. This could be due to increased importance of data services and smartphones bundles. It should also be born in mind that due to the small size of the country, a substantial part of the mobile costs arises from roaming charges. Although EU is pushing all operators to reduce these charges, this was not visible yet in 2011.

| Development index | 2002 | 2007 | 2008 | 2010 | 2011 |
|---|---|---|---|---|---|
| IDI | 4,62 | 7,03 | 7,71 | 7,78 | 7,76 |
| Rank | 21 | 7 | 2 | 7 | 7 |
| Access | 6,68 | 8,6 | 8,8 | 8,8 | 8,87 |
| Rank | 11 | 2 | 2 | 3 | 3 |
| Use | 1,4 | 5,56 | 7,09 | 7,24 | 7,07 |
| Rank | 22 | 2 | 1 | 3 | 7 |
| Skills | 6,91 | 6,84 | 6,77 | 6,79 | 6,9 |
| Rank | 62 | 75 | 82 | 87 | 81 |

_Table 10: ITU Development Index (source: ITU)

In terms of IDI, major improvements have been made improvements between 2002 and 2008 mainly in terms of Access and Use and the country ranks amongst the top 10 in the world and even in the top 3 in terms of Access. This can be explained by the development of the underlying telecommunications infrastructure and international connectivity (Binsfeld et al., 2013) and by the development of usage of PCs and internet by Households as seen above. However, in line with the NRI findings

| Indicator | Value | Rank | Year |
|---|---|---|---|
| Ind. Portable devices to access internet | 60% | 1 | 2010 |
| Supply chain management | 27% | 3 | 2010 |
| HH health information | 66,3% | 3 | 2010 |
| HH Internet for Learning | 73% | 4 | 2010 |
| HH Internet for communications | 85% | 5 | 2010 |
| Households Internet Access | 90,60% | 6 | 2011 |
| HH Internet for gaming | 38% | 6 | 2010 |
| Receiving invoices | 33% | 6 | 2010 |
| HH Web pages | 18% | 7 | 2011 |
| Employees using computers | 57% | 7 | 2011 |
| HH Internet for E-commerce | 53% | 8 | 2011 |
| HH Internet for Banking | 58% | 8 | 2011 |
| ICT specialists | 4,50% | 8 | 2010 |
| Wireless Broadband | 66,10% | 10 | 2011 |
| Senior 55-64 using the internet | 73% | 10 | 2011 |
| Intranet | 35% | 12 | 2010 |
| Internal file sharing | 56% | 12 | 2010 |
| Share of ICT sector employment | 6% | 13 | 2009 |
| Businesses using the internet | 97% | 13 | 2011 |
| HH Social Networking | 52% | 14 | 2011 |
| B with BB connection | 95% | 14 | 2011 |
| B Web sites | 75% | 15 | 2011 |
| HH Internet for information from public authoritie | 40% | 17 | 2011 |
| HH Peer-to-peer file sharing | 18% | 18 | 2011 |
| Buying online | 30% | 18 | 2010 |
| HH Internet for Job search | 13% | 20 | 2011 |
| Ind. Social Networking | 44% | 20 | 2010 |
| Awareness of security obligations | 36% | 21 | 2010 |
| Fibre Broadband Penetration | 0,80% | 25 | 2011 |
| Forms to authorities | 63% | 25 | 2011 |
| Ind. Gender gap | 8% | 28 | 2011 |

_Table 11: Indicators for Luxembourg (source: OECD Internet Economy Outlook 2012)

As the number of countries included in these indicators is not always the same, the absolute ranking positions may not be comparable. Therefore, only a general classification was used – ranks 1-10 are defined as "amongst the top 10 OECD countries", 11-20 as "around OCED average", rank 21 and higher as "lagging behind".

In terms of Internet Economy, it can be seen that Luxembourg shows relatively little awareness of security issues which is surprising given the importance of the financial sector and the

47_The 2002 values have been recalculated by ITU from previous indices to allow for comparisons on the IDI.

48_http://www.oecd.org/internet/broadband/oecdkeyictindicators.htm accessed 17.7.2013 fact that many ICT providers need to have the "Professionnel du Secteur Financier (PSF)[49]" status to be allowed to offer services to the financial sector, that the Government has issued a national e-security plan (SMC, 2011) and that Luxembourg has set up its own certification authority[50].

Luxembourg also did lack behind on "fibre connectivity" – however this issue has been addressed (SMC, 2010), (SMC, 2009) and future assessments should show significant improvements in this area. The two other weak points are, a relatively important gender gap – women are far less present in ICT roles and appear to be less fluent as well and finally e-Government as many administrations seem still to have issues with e-forms.

The share of ICT specialists appears to be higher than average and this might, yet again be linked to the importance of ICT for the financial sector and confirms findings presented above. According to OECD, Luxembourg is considered "average" on many indicators related to internet and e-commerce usage by individuals and business. However, Luxembourg does also rank amongst the top 10 in several other indicators related to internet usage and in particular mobile internet usage. It can be argued, that access to the internet and its usage is in line with many other OECD countries. Having a deeper look into a set of different price baskets, it appears prices for most services are towards the higher end or, at best, average. Often these values are expressed as a ratio of GNI or GDP and Luxembourg appears to score well. This, however is due to the very high GDP[51] rather than to low prices for communication services. Overall, telecommunications price levels for both businesses and individuals, according to OCED price basked, appear to be less attractive than in most other OECD countries.

There are however, some products and services for which Luxembourg scores well, again these appear to be more on the mobile side. Mobile devices, smartphones and tablets seem to be appreciated by local customers, average monthly revenue per user is amongst the highest in OECD, just as the total revenue as well as the total spending per capita. Mobile subscriptions, digital TV and cable TV networks are amongst the highest countries as well and service bundles appear to be very popular again confirming previous findings.

On the other hand, according to OECD, Luxembourg has a well-developed internet infrastructure, it ranks second behind France in terms of IPv4[52] addresses per capita, IPv6[53] networks and content delivery and scores well on autonomous systems[54] (ASN), and country-code top level domains[55] (ccTLD). Domain .lu names[56] grow scores far less well and this might be explained by relatively high costs to register such a local domain name.

| Indicator | Value | Rank | Year |
|---|---|---|---|
| Total paths per 100 inhabitants | 235 | 1 | 2011 |
| Net additions fixed phones | 6% | 1 | 2009-2011 |
| IP v6 users | 2,60% | 2 | 2012 |
| Data only 2 GB | 9 USD/PPP | 2 | 2012 |
| Investment per capita | 300 USD | 3 | 2011 |
| Routed AS numbers/100.000 inh. | 9,20% | 3 | 2012 |
| Share of ASN IPv6 ready | 47% | 3 | 2012 |
| Content available over Ipv6 | 55% | 3 | 2012 |
| Use of Smartphones to access Inet | 34% | 3 | 2011 |
| Telecom revenue/capital | 1400 USD | 4 | 2011 |
| Leased Lines 34Mbit/ | 3000 USD/PPP | 4 | 2012 |
| Tablet 2 GB | 10 USD/PPP | 4 | 2012 |
| Investment per path | 130 USD | 5 | 2011 |
| Mobile sucriptions per 100 inh. | 150 | 5 | 2011 |
| CableTV | 68% | 5 | 2011 |
| Data only 1GB | 9 USD/PPP | 5 | 2012 |
| Country relatad ccTLD reg. | 140 | 6 | 2012 |
| Secure Web server /100000 inh | 220 | 6 | 2012 |
| Bundles | 56% | 6 | 2011 |
| Share of mobile | 52% | 8 | 2011 |
| ARPU | 40 USD | 8 | 2011 |
| Routed IPv4 addresses per capita | 1,9 | 9 | 2012 |
| Data only 500 MB | 9 USD/PPP | 9 | 2012 |
| Data only 10 GB | 25 USD/PPP | 9 | 2012 |
| Penetration of digital TV | 92% | 10 | 2011 |
| Tablet 1GB | 10 USD/PPP | 10 | 2012 |
| Wireless Broadband | 68% | 11 | 2012 |
| IPTV | 13% | 11 | 2011 |
| 30 Calls plus 100 MB mobile | 17 USD/PPP | 11 | 2012 |
| 900 Calls plus 2 GB mobile | 45 USD/PPP | 11 | 2012 |
| Fixed broadband | 33% | 12 | 2012 |
| Telecom revenues per access path | 580 USD | 13 | 2011 |
| Data only 5 GB | 25 USD/PPP | 14 | 2012 |
| Tablet 500 MB | 10 USD/PPP | 14 | 2012 |
| Tablet 250 MB | 10 USD/PPP | 15 | 2012 |
| Tablet 5 GB | 20 USD/PPP | 15 | 2012 |
| 300 Calls plus 1 GB mobile | 40 USD/PPP | 16 | 2012 |
| 100 Calls plus 2 GB mobile | 45 USD/PPP | 17 | 2012 |
| Broadband fixed low basket 2GB | 28 USD/PPP | 18 | 2012 |
| 100 Calls plus 500 MB mobile | 32 USD/PPP | 18 | 2012 |
| Digital terrestrial television | 8% | 20 | 2011 |
| Monthly HH expenditure | 140 USD/PPP | 20 | 2011 |
| Broadband fixed low basket 14GB | 45 USD/PPP | 22 | 2012 |
| Broadband fixed high basket 42 GB | 55 USD/PPP | 24 | 2012 |
| Fibre connections | 2,00% | 25 | 2012 |
| Dial up | 4% | 25 | 2011 |
| Broadband fxed low basket 18 GB | 60 USD/PPP | 25 | 2012 |
| Broadband fixed high basket 54GB | 60 USD/PPP | 25 | 2012 |
| Bit/data caps | 45% | 27 | 2012 |
| Broadband fixed low basket 6GB | 35 USD/PPP | 28 | 2012 |
| Annual growth .lu domain names | 15% | 29 | 2000-2012 |
| Broadband fixed low basket 11GB | 55 USD/PPP | 29 | 2012 |
| Broadband fixed high basket 18 GB | 46 USD/PPP | 30 | 2012 |
| Broadband fixed high basket 33 GB | 55 USD/PPP | 30 | 2012 |
| Broadband fixed high basket 6GB | 37 USD/PPP | 31 | 2012 |
| Mobile Termination rates | 0.12 USD | 34 | 2012 |

_Table 12: Indicators for Luxembourg (source: OECD Communications Outlook 2013)

## 4.3.4_ The World Bank Knowledge Economy Index

The Knowledge Economy Index framework of the World Bank allows to explore further the issues around education identified above, bearing in mind however, that the KEI is only available for 1995, 2000 and 2012.

In ranking terms (The World Bank, 2012a), Luxembourg has achieved an improvement from 2000 to 2012 and has made it into the top 20 countries. However, in absolute terms the KEI has decreased from 8.51 in 2000 to 8.37 in 2012. Looking into the 4 constituents of the KEI: economic and institutional regime, education, ICT and innovation the following scores can be identified and it can be seen that Luxembourg scores badly on the education indicator.

| | KEI | Ranking | Economic Incentive Regime | Rank | Innovation | Rank | Education | Rank | ICT | Rank |
|---|---|---|---|---|---|---|---|---|---|---|
| 1995 | 8,42 | 10 | 9,23 | 8 | 8,92 | 13 | 6,08 | 39 | 9,45 | 7 |
| 2000 | 8,52 | 22 | 9,6 | 2 | 8,92 | 11 | 6,38 | 34 | 9,14 | 9 |
| 2012 | 8,37 | 20 | 9,45 | 6 | 8,94 | 11 | 5,61 | 40 | 9,47 | 2 |

_Table 13: KEI evolution (source: World Bank)

Dwelling deeper into the underlying variables, it turns out that, just as for NRI above, it is "tertiary" enrolment rate, collected from an UNESCO database, that the country scores worst and this leads to very low rank on this sub-index. Unfortunately, the situation does not seem to have improved over time.

| | |
|---|---|
| Adult Literacy Rate (% age 15 and above), 2007 | 10.00 |
| Average Years of Schooling, 2010 | 7.24 |
| Average Years of Schooling, female, 2010 | 6.69 |
| Gross Secondary Enrollment rate, 2009 | 7.31 |
| Gross Tertiary Enrollment rate, 2009 | 2.27 |
| Life Expectancy at Birth, 2009 | 8.97 |
| Internet Access in Schools (1-7), 2010 | 8.85 |
| Public Spending on Education as % of GDP, 2009 | n/a |
| 4th Grade Achievement in Math(TIMSS), 2007 | n/a |
| 4th Grade Achievement in Science(TIMSS), 2007 | n/a |
| 8th Grade Achievement in Math(TIMSS), 2007 | n/a |
| 8th Grade Achievement in Science(TIMSS), 2007 | n/a |
| Quality of Science and Math Education (1-7), 2010 | 6.87 |
| Quality of Management Schools (1-7), 2010 | 5.57 |
| 15-year-olds' math literacy (PISA), 2009 | 5.74 |
| 15-year-olds' science literacy (PISA), 2009 | 4.43 |
| School Enrollment, Secondary, Female (% gross), 2009 | 7.29 |
| School Enrollment, Tertiary, Female (% gross), 2009 | 2.11 |
| No Schooling, total, 2010 | 5.04 |
| No Schooling, female, 2010 | 5.20 |
| Secondary School completion ,total (% of pop 15+), 2010 | 6.93 |
| Secondary School completion ,female (% of pop 15+), 2010 | 7.09 |
| Tertiary School completion ,total (% of pop 15+), 2010 | 6.69 |
| Tertiary School completion ,female (% of pop 15+), 2010 | 6.69 |

_Table 14: Educational Assessment Variables and scores (source: World Bank)

49_http://www.luxembourgforfinance.lu/psf accessed 17.7.2013

50_https://www.luxtrust.lu/en accessed 17.7.2013

51_http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/GDP_per_capita,_consumption_per_capita_and_price_level_indices accessed 17.7.2013

52_http://www.ripe.net/ripe/docs/ripe-592 accessed 17.7.2013

53_http://www.worldipv6launch.org/ accessed 17.7.2013

54_http://www.apnic.net/services/services-apnic-provides/helpdesk/faqs/asn-faqs accessed 17.7.2013

55_http://www.iana.org/domains/root/db accessed 17.7.2013

56_http://www.dns.lu/ accessed 17.7.2013

On the other hand, the country scores world-wide second in terms of ICT access and infrastructures, which is in line with the findings from WEF and ITU and almost stable on the other two sub-indexes.

### 4.4_ Commercial organisations

### 4.4.1_ The "Booz&Co" Digitisation Index

A first set of results has been presented recently at the EURO-CRP 2013[57] conference. This puts Luxembourg amongst the top performers – the so-called "advanced" countries

Unfortunately, the breakdown according to the different sub-indices is not publicly available. In particular it would have been useful to have access to the "skills" subindex.

When looking at the correlation between GDP/capita and DI, however, it can be seen that Luxembourg does actually score below what would be expected given its top position in terms of GDP per capita.

### 4.4.2_ Cisco Broadband Quality Score

Luxembourg was included in this assessment from 2008 to 2010. In 2008 and 2009, Luxembourg was classified into

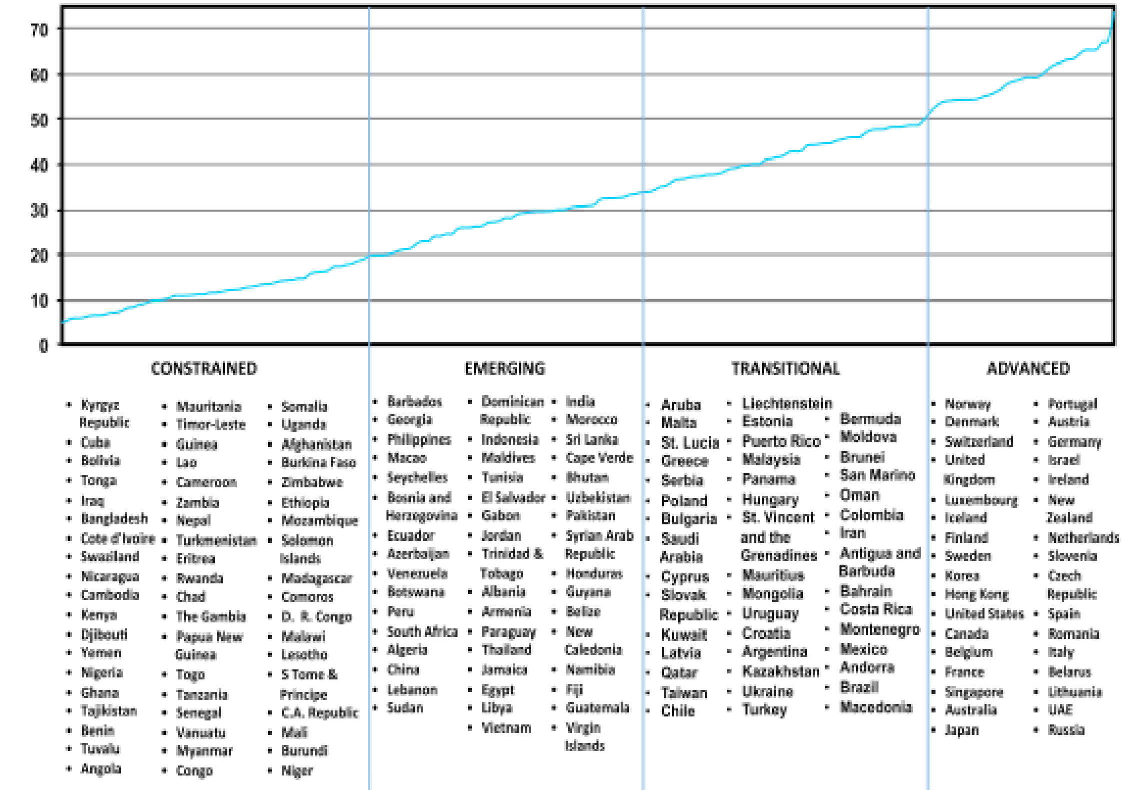


_Fig. 16: The digitisation Index (source: Euro-CRP 2013)

In 2011, Luxembourg scored third amongst the EU27 countries just behind Denmark and the UK. It scored 7th on a global scale with a score of 65 which is 10 above the EU27 average. Looking at the development between 2004 and 2010, its score has improved by 224% which shows that the initiatives that have been taken in terms of infrastructure have been successful.

"ready for today's applications" countries with ranks 30 and 24 respectively – a good improvement in only one year. In 2010, Luxembourg was classified into "ready for today's applications" but qualified as a "broadband leader" with rank 7 amongst "innovation economies" and rank 16 in terms of mobile broadband. Again this seems to indicate a good improvement. However, it should be noted that about 14

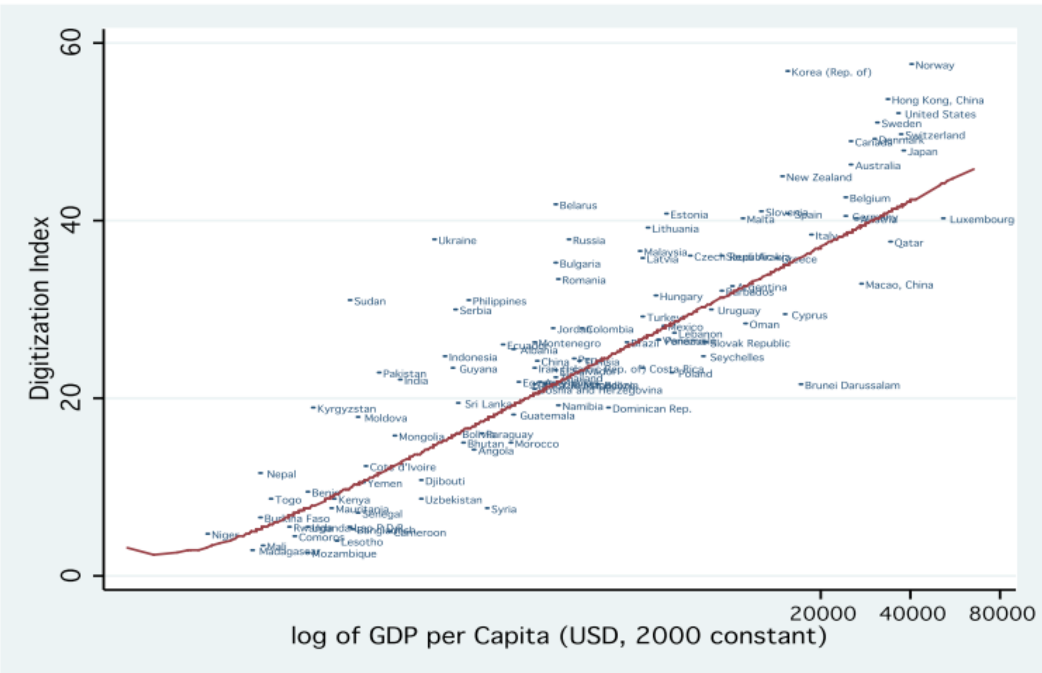


_Fig. 17: Correlation GDP-Capita/DI (source: Euro-CRP 2013)

57_http://www.eurocpr.org/ accessed 18.7.2013 countries were classified into "ready for tomorrow's applications" as opposed to only 1 in 2008 which suggests an overall improvements amongst many countries. The BQS therefore suggests some improvements but it is not clear whether these did actually happen or whether it was just a change in the methodology. Unfortunately, there is not enough information available about the underlying methodology to come up with a more precise view.

### 4.5_ Measuring the internet

In addition to these ad-hoc indicators, it is also interesting to look at Netindex values which are collected on a rolling yearly basis. No information is available for Luxembourg in terms of quality index. All other indicators are available with about 550 samples collected over the last year. This gives in indication for the overall available downlink and uplink speed, the relative costs of services and the so-called "promise", meaning the ratio between speed advertised by operators and those actually achieved. As expected, Luxembourg, because of its high GDP/capita, ranks very well on the cost indicators and ranks amongst the top 10 countries for uplink and 12th for downlink speeds. In terms of the promise index, there is still room for improvement with rank 44. Of course, these values need to be treated with care as they can change on a daily basis – but they give a good, almost online indication about the broadband traffics actually achieved.

| | |
|---|---|
| Download (Mbit/s) | 31,5 |
| Ranking | 12 |
| Upload (Mbit/s) | 20,04 |
| Raking | 7 |
| Relative cost of Broadband (% of GDP/Capita) | 0,589 |
| Ranking | 1 |
| Relative cost of Mbit/s | 0,05% |
| Ranking | 2 |
| Household Promise Index (%) | 83,21 |
| Ranking | 44 |

_Table 15: Netindex values for Luxembourg on the 14.7.2013 (source: Netindex)

In terms of the Akamai – state of the internet 2013 report, Luxembourg appears to score badly on the average available connection speed and even more so on the peak connection speed. This is surprising given the fact the underlying technical infrastructures are well developed and not in line with the Netindex assessment above. However, Akamai states in its comments that it only considers countries with more than 25.000 IP addresses that made request for content on their platforms. Therefore the figures might not be completely reliable as a lot depends on the actual web sites accessed. It should also be noted that the global average connection speed was identified as 3.1 Mbps and the global average peak connection speed at 18.4 Mbps both values being far lower that the results for Luxembourg.

| Country | Average connection speed (Mbps) | Country | Peak Connection Speed (Mbps) |
|---|---|---|---|
| Switzerland | 10,1 | Romania | 47,9 |
| Netherlands | 9,9 | Switzerland | 40,3 |
| Czech Republic | 9,6 | Netherlands | 38,2 |
| Sweden | 8,9 | Belgium | 38 |
| Denmark | 8,3 | United Kingdom | 36,3 |
| Austria | 7,9 | Hungary | 35,9 |
| United Kingdom | 7,9 | Czech Republic | 35,5 |
| Finland | 7,7 | Sweden | 34,9 |
| Romania | 7,5 | Portugal | 34,5 |
| Belgium | 7,4 | Poland | 32,2 |
| Norway | 7,4 | Spain | 31,3 |
| Ireland | 7,3 | Ireland | 30,9 |
| Germany | 6,9 | Germany | 30,8 |
| Hungary | 6,6 | Austria | 30,6 |
| Slovakia | 6,4 | Denmark | 29,5 |
| Iceland | 6,3 | Iceland | 29,3 |
| Poland | 6,2 | Russia | 29,3 |
| Russia | 6 | Finland | 29,2 |
| Luxembourg | 5,3 | Slovakia | 29,1 |
| Portugal | 5,3 | Norway | 28,7 |
| France | 5,2 | Greece | 25,5 |
| Spain | 5,2 | Turkey | 25 |
| Greece | 4,7 | France | 23,5 |
| Italy | 4,4 | Italy | 21,8 |
| Turkey | 3,1 | Luxembourg | 21,5 |

_Table 16: Average and peak connection speeds to the Internet (source: Akamai)

### 4.6_ The efficiency of the national regulatory authority

#### 4.6.1_ Telecommunications Regulation Index

Finally, it can be useful to have a look at the performance of the NRA according to the Polynomics Telecommunications Regulation Index. There are two versions of this index. The first, called RDI24, is focusing on "traditional fixed and mobile services", the second, called RDI37, also includes additional aspects for next generation networks.

The RDI24 is available as a time series starting in 1997 (Zenhäusern, Schneider, Berner, & Vaterlaus, 2012). Luxembourg presents a very low so called "regulation density"; actually it is the lowest (0.32) in the overall sample which includes all EU member states but also the US and Australia. This density has not evolved over the last 5 years. Cyprus, Slovenia and Spain present the highest regulator densities in the EU with a value of around (0.70).

On the RDI37, a time series is only available down to 2008 and it is again Luxembourg that presents the lowest regulatory density (0.26) of all of the countries considered in the study. Overall, it can also be seen, that the values for all of the NRAs are lower on the RDI37 as they have less experience in regulating NGA.

This could indicate that ILR takes an overall quite "laid-back" approach to its regulatory task and does not intervene very much in the market. More information would be needed in order to understand whether this due to a lack of resources or an intentional political approach to leave space market forces.

#### 4.6.2_ Telecommunications Regulatory Governance Index

In terms of the Telecommunication Regulatory Governance Index (TRGI) (Waverman & Koutroumpis, 2011), Luxembourg scored 34 in the Global ranking and 19 for the regional rank in 2008. Only the new EU member states from Central and Eastern Europe performed less well.

This seems to confirm the findings in the Polynomics approach above although the underlying methodology is a completely different one. It can also be noted that compared to a relatively high "overall political transparency", Luxembourg scores poorly which could suggest that the regulator does less well than other Government agencies and the general economic governance in the country. Obviously, one would need to have access to more recent data and a time series in order to be able to draw more definite conclusions. It is also not clear which underlying factor (regulatory transparency, independence, resource availability or enforcement on licensees) contributes most to this low ranking.

## 5_ Summary of the major findings

In this chapter, the authors will summarise the main findings as they appear through the different indicators assessed above.

Not surprisingly, the telecommunications of Luxembourg is a very small one in absolute terms but the share of ICT both in terms of value added and jobs created is higher than in most other EU or OECD countries. Having said this, there is close to none ICT manufacturing, very little ICT R&D and the bulk of the revenues in the sector are generated through services. This might be linked to the importance of the financial sector (KPMG, 2012), (Bourgain, Pieretti, & Høj, 2009) for Luxembourg's economy overall (OECD, 2012a), a financial sector which is relying extensively on ICT.

The mobile telecommunications market is more important than the fixed network one and the gap between the two is continuing to grow. Internet access and broadband internet access are playing a major role and are well developed, consumers are attracted by triple and quadruple play service bundles, average monthly revenue per user is high, just as the overall telecommunications revenues (on a per capita basis), and they continue to grow.

In the mobile market, there is competition with 3 mobile 2G/3G/LTE operators, the fixed residential market is largely in the hand of the incumbent operator. For enterprise customers, there is a growing competition in recent years but the incumbent also is the largest player this sector. 100% of the population has access to the internet, almost all homes are using a personal computer and wireless broadband using 2G/3G. Wireless Lan is present in the main population areas. Internet infrastructure is well developed in Luxembourg. Luxembourg scores very well on IPv6 deployment (Tadayoni & Henten, 2012), autonomous systems and country code Top Level Domains as well as on several "on-line" performance measures. Cable TV networks are also well developed in Luxembourg but they face a fierce competition by different IPTV services.

In line with Europe's 2020 goals, Luxembourg has defined an ultra-high broadband strategy based on fibre to the home roll-out and the incumbent has been given the mandate and the resources to build the underlying infrastructures. Recently, these resources have even been extended in an effort to stimulate the local economy with a so-called "Marshall Plan" (Di Pillo, 2013), (Cortey, 2013).

In the period between 2005 and 2009, Luxembourg did lose out in terms of its position in international rankings as can be documented by the NRI and IDI. The Government did put in place several actions to develop Luxembourg's international connectivity and create datacentre capacity (Binsfeld et al., 2013). This has positioned Luxembourg as one of the world's largest providers of TierIV datacentre capacity and has led to excellent broadband connectivity to the main European Peering Hubs.

Considerable improvements can be noted on both indices in recent years as a consequence. This is confirmed also by the DAE scoreboard, by the digitisation index and by regular measurements directly on the internet. Access to the internet and the underlying infrastructure is not a problem in Luxembourg anymore, the technological issues have been addressed successfully.

In terms of affordability, the situation is less positive as prices for many ICT services are still towards the higher range compared to other EU or OECD countries. In many indicators, this does not become visible because prices are often measured as a percentage of GDP/capita or GNI/capita. On an absolute basis however, the situation is not so favourable and ITU's IPB also shows that no substantial improvements have been made over time.

One reason behind these relatively high prices might be the very high investments that operators (mainly the incumbent) have made for a relatively small market. However, it could also be argued that it might be the lack of active competition that has allowed operators to keep their pricing levels high. This hypothesis might be confirmed by the very low ranking achieved by the national regulatory authority, in fact the lowest of all countries considered. This shows that the regulator has not been able or willing to intervene very much with the market forces.

Whilst almost all businesses and households make good use of the internet, e-commerce is not very well developed within Luxembourg and a large part of it is buying from international e-commerce providers. This could be explained by the small size of the country and the limited size of the market. However, Luxembourg does still have room for improvement in order to fully exploit its legal environment allowing it to set up e-commerce operations out of Luxembourg, other than offering an attractive "tax haven" to some international e-commerce players (Binsfeld et al., 2013).

More generally, Luxembourg appears to take some advantage out of its role as founding member of the EU, its geographical location and its small size that leads to a certain flexibility and as WEF calls it – its "vision for ICT". Thus it ranks world-wide first on the indicator "laws related to ICT". However, there are also some issues identified in terms of the number of processes to set up a company, the accessibility of authorities via the internet, the usage of electronic forms which appear to restrict somewhat these potential advantages.

A major issue identified in several indicators appears to be an inappropriate educational system and in particular a very low "tertiary enrolment rate". This has a major effect on both NRI and IDI rankings and is confirmed by the studies from World Bank.

It might well be that all 3 organisations are using the same underlying databases (from Unesco?) but nevertheless the issue appears to be serious one as shown for example by the several weaknesses that WEF has identified for Luxembourg's educational system, the very low rank on this specific sub-index in the IDI and in the KEI from World Bank. Even worse, no improvements seem to have been made over time in this respect but according to IDI the situation even got worse.

As a consequence, ICT skills need to be imported from neighbouring countries or even from abroad which gets increasingly more difficult and companies appear to have substantial difficulties to recruit skilled ICT workers.

**6_ Conclusions and future work**

Despite the many different limitations and methodological problems of measuring the information society, it was possible, using a wide range of different indicators and indices, to conduct an assessment of Luxembourg's ICT state of development, to gain a good understanding of its strengths and weaknesses and to answer the two research questions identified above:

_Luxembourg does position itself amongst the top performers in the EU and worldwide with regard to ICT. Its ICT sector is well developed and constitutes and important part of its economy.
_Luxembourg has been able, over the last decade or so, to improve this position and in particular was able to extend the underlying technical infrastructures and to develop the use of ICT and therefore overall its e-Readiness. It has not been successful, however, in improving the skills and educational aspects related to ICT.

However, the combined indicators above also have allowed to identify many additional important questions for which they do not provide the answers and which require additional work:

_Is the country's focus on TierIV datacentre capacity really appropriate, why does it have 20% of the world's overall capacity? Is there a deliberate decision by other countries not to focus on this category?
_Is it really necessary and economically sensible to roll-out a nationwide fibre to the home network given the fact that there is substantial cable TV network coverage in place already?
_Why is the regulation density so low in comparison with other OECD countries? Is this a lack of resources or a political decision?
_Why are businesses and individuals and the government not more actively using e-transactions and local e-commerce offerings?
_Is the country taking appropriate advantage from its "flexibility" ,small size and political vision?
_Is the country taking appropriate advantage from its relative "richness" with one of the highest GDP/capita in the world?
_What exactly is the issue with regards to education and skills? Are the country's university and research centres focussing on the "right" areas of competences? Is there a deeper underlying problem with the country's educational system? Or is it just a matter of reporting the "right" figures

Clearly these questions can't be addressed on a purely technical or ICT level. They have to be looked at from the wider socio-economic perspective.

Whilst this might be achieved on a purely quantitative basis by making use of a wider range of indices and assessment framework as presented for example in Bandura (2008) or Taylor & Cui (2011), the authors' believe it will also be necessary to collect qualitative information directly from the different stakeholders involved in order to gain a deeper understanding and to be able to address at least some of issues which might be essential for Luxembourg's long-term well-being.

**Bibliography**


Airoldi, M.-J. (2012). Le comportement des Luxembourgeois face aux nouvelles technologies de l'information et la communication depuis le début des années 60 (Le Luxembourg 1960-2010). Luxembourg. Retrieved from www.statec.public.lu

Akamai. (2013). The State of the Internet 2013 (Vol. 6).

Annoni, P., Weziak-Bialowolska, D., & Nardo, M. (2012). Assessment of the Web Index uncertainty analysis. JRC Scientific and Policy Reports (Vol. EUR 25476).

Arbor Networks. (2012). Infrastructure Security Report 2012 Volume VIII (Vol. VIII).

Bandura, R. (2008). A Survey of Composite Indices Measuring Country Performance : 2008 Update. New York. Retrieved from http://web.undp.org/developmentstudies/docs/indices_2008_bandura.pdf

Bauer, S., Clark, D., & Lehr, W. (2010). Understanding broadband speed measurements (MITAS Working Paper).

Bilbao-Osorio, B., Dutta, S., & Lavin, B. (Eds.). (2013). The Global Information Technology Report 2013 Growth and Jobs in a Hyperconnected World (2013th ed.). Geneva: World Economic Forum.

Binsfeld, N., Whalley, J., & Pugalis, L. (2013). Luxembourg – a bastion of state-ownership in Europe. International Telecommunications Society Regional Conference. Brussels.

Bourgain, A., Pieretti, P., & Høj, J. (2009). Can the Financial Sector continue to be the Main Growth Engine in Luxembourg ? (OECD Economics Department Working Papers No. 660). Paris. Retrieved from www.oecd.org

Chen, D. H. C., & Dahlman, C. J. (2005). The Knowledge Economy , the KAM Methodology and World Bank Operations.

Cisco & Saïd Busines School. (2008). Broadband Quality Score A global study of broadband quality 2009.

Cisco & Saïd Busines School. (2010). Broadband quality score 2010.

Cortey, L. (2013, June 20). Le Luxembourg monte en puissance. Luxemburger Wort, p. 49. Luxembourg.

Cruz-Jesus, F., Oliveira, T., & Bacao, F. (2012). Digital divide across the European Union. Information & Management, 49(6), 278–291. http://doi.org/10.1016/j.im.2012.09.003

Di Pillo, N. (2013, May 10). 2,5 milliards d'euros à investir. Luxemburger Wort, p. 69. Luxembourg.

Dutta, S., & Bilboa-Osoria, B. (2012). The Global Information Technology Report 2012 Living in a Hyperconnected World. (S. Dutta & B. Bilbao-Osorio, Eds.). World Economic forum.

Dutta, S., Lavin, B., & Fiona, P. (2003). Global Information Technology Report 2002-2003: Readiness for the Networked World. Oxford University Press. Retrieved from http://ictlogy.net/bibliography/reports/projects.php?idp=401

EIU. (2010). Digital economy rankings 2010 Beyond e-readiness. Retrieved from http://www.eiu.com/site_info.asp?info_name=digitaleconomy_2010

Empirica. (2002). SIBIS Highlights 2002.

Empirica. (2003). SIBIS Pocket Book 2002/03.

European Commission. (1990). Directive on competition in the markets for telecommunications services. Brussels: EC. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1990:192:0010:0016:EN:PDF

European Commission. (2003). SIBIS New eEurope Indicator Handbook.

European Commission. (2009). Europe's Digital Competitivenss Report i2010 - ICT country profiles (Vol. 2).

European Commission. (2010a). A Digital Agenda for Europe. EU.

European Commission. (2010b). Europe's Digital Competitiveness Report 2010.

European Commission. (2010c). Implementation Reports. Retrieved from http://ec.europa.eu/information_society/policy/ecomm/library/communications_reports/index_en.htm

European Commission. (2011). Digital Agenda Scoreboard 2011.

European Commission. (2012a). Digital Agenda Scoreboard 2012.

European Commission. (2012b). Telecommunication Market and Regulatory Developments Luxembourg 2011.

European Commission. (2013a). Broadband coverage in Europe in 2011. Brussels. Retrieved from http://point-topic.com/wp-content/uploads/2013/11/Point-Topic-Broadband-Coverage-in-Europe-in-2012-Final-Report-20130813.pdf?utm_campaign=EU_publishes_Broadband_Coverage_in_Europe_study&utm_medium=Email&utm_source=CM_pointtopic

European Commission. (2013b). Digital Agenda Scoreboard 2013.

European Commission. (2013c). Digital Agenda Scoreboard 2013 Electronic communications market indicators : Definitions , methodology and footnotes on Member States. Brussels.

European Commission. (2013d). Digital Agenda Scoreboard key indicators. Retrieved from http://digital-agenda-data.eu/datasets/digital_agenda_scoreboard_key_indicators/indicators

Eurostat. (2011). Implementing core variable in EU social survey - methodological guidelines (Vol. 12).

Eurostat. (2012). Information society statistics. Retrieved from http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Information_society_statistics

Eurostat. (2013). Methodological Manual for statistics on the information society. Retrieved from http://epp.eurostat.ec.europa.eu/portal/page/portal/information_society/introduction

Friedrich, R., Stroh, S., & Vollmer, C. (2012). The 2012 Industry Digitization Index.

Frising, A. (2013). Regards sur les internautes au Luxembourg et dans l'UE27 (Regards No. Mai 2013). Luxembourg. Retrieved from http://www.statistiques.public.lu/fr/actualites/conditions-sociales/conditions-vie/2013/05/20130515/index.html?from=rss

Frising, A., & Niclou, P. (2012). Regards sur les technologies de l ' information et de la communication dans les ménages. Luxembourg. Retrieved from www.statistiques.lu

Goswami, D. (2006a). A review of the Network Readiness Index. Retrieved from www.regulateonline.org

Goswami, D. (2006b). Report on Workshop on ICT Indicators for Benchmarking Performance in Network and Services Development.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). Multivariate Data Analysis - a global perspective (7th ed.). Upper Saddle River, New Jersey: Pearson Education.

Hüsing, T. (2004). THE IMPACT OF ICT ON SOCIAL COHESION : LOOKING BEYOND THE DIGITAL DIVIDE.

Hüsing, T., & Selhofer, H. (2004). DIDIX : A D IGITAL D IVIDE I NDEX FOR M EASURING I NEQUALITY IN IT D IFFUSION. IT&Society, 1(7), 21–38. Retrieved from www.itandsociety.org

i2010 High Level Group. (2009). Benchmarking Digital Europe 2011-2015.

ILR. (2004a). Rapport statistique année 2003. Luxembourg. Retrieved from www.public.ilr.lu

ILR. (2004b). Rapport statistique succinct Année 2004. Luxembourg. Retrieved from www.public.ilr.lu

ILR. (2005). Rapport statistique des télécommunications au Luxembourg pour l'année 2005. Luxembourg. Retrieved from www.public.ilr.lu

ILR. (2006). Rapport statistique des télécommunications au Luxembourg pour l ' année 2006. Luxembourg. Retrieved from www.public.ilr.lu

ILR. (2007). Rapport statistique des télécommunications au Luxembourg pour l'année 2007. Luxembourg. Retrieved from www.public.ilr.lu

ILR. (2008). Rapport statistique des télécommunications Luxembourg pour l ' année 2008. Luxembourg. Retrieved from www.public.ilr.lu

ILR. (2009). Rapport statistique des télécommunications Luxembourg pour l'année 2009. Luxembourg. Retrieved from www.public.ilr.lu

ILR. (2010). Rapport statistique des télécommunications au Luxembourg pour l ' année 2010. Luxembourg. Retrieved from www.public.ilr.lu

ILR. (2011). Rapport statistique des télécommunications du Luxembourg de l'année 2011. Luxembourg. Retrieved from www.public.ilr.lu

ILR. (2012). Registre public des entreprises notifiées fournissant des services aux consommateurs. Luxembourg.

ILR. (2013). Rapport statistique des télécommunications du Luxembourg de l'année 2012. Luxembourg. Retrieved from http://www.ilr.public.lu/communications_electroniques/statistiques/rapp_statistiques_ILR/2012_rapport_statistique_final1.pdf

INSEAD. (2005). eEurope2005 A study of the degree of alignment of the new member states and the candidate countries. (INSEAD, Ed.). SAP. Retrieved from http://www.umic.pt/images/stories/publicacoes/Misc_ eEurope_2005.pdf

ITU. (2009). Measuring the Information Society 2009. Retrieved from http://www.itu.int/ITU-D/ict/publications/idi/

ITU. (2010). Measuring the Information Society 2010. Retrieved from http://www.itu.int/ITU-D/ict/publications/idi/

ITU. (2011a). Handbook for the collection of administrative data on Telecommunications/ICT (2011th ed.). Geneva. Retrieved from http://www.itu.int/dms_pub/itu-d/opb/ind/D-IND-ITC_IND_HBK-2011-PDF-E.pdf

ITU. (2011b). Measuring the Information Society 2011. Retrieved from http://www.itu.int/ITU-D/ict/publications/idi/

ITU. (2011c). Measuring the WSIS targets - a statistical framework. Geneva.

ITU. (2012). Measuring the Information Society 2012. Retrieved from http://www.itu.int/ITU-D/ict/publications/idi/

Katz, R. L. (2013). Using a Digitization Index to measure the Economic and Social Impact of Digital Agendas. In Euro CRP 2013 A digital agenda in search of evidence: Issues and Trends Brussels, Belgium March 21 (Vol. 2013).

Katz, R. L., & Koutroumpis, P. (2013). Measuring digitization: A growth and welfare multiplier. Technovation, 0–5. http://doi.org/10.1016/j.technovation.2013.06.004

KPMG. (2012). Luxembourg Banks Insights 2012. Luxembourg.

Lehr, W. (2012). Measuring the Internet THE DATA CHALLENGE (OECD Digital Economy Papers No. 194). Paris. Retrieved from http://dx.doi.

org/10.1787/5k9bhk5fzvzx-en

Luyt, B. (2006). Defining the digital divide: the role of e-readiness indicators. Asib Proceedings, 58(4), 276–291. http://doi.org/10.1108/00012530610687669

Mas, M., Robledo, J. C., & Perez, J. (2012). ICT Sector Definition Transition from NACE Rev . 1 . 1 to NACE Rev . 2 A Methodological Note. Luxembourg. Retrieved from http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=5919

Menou, M. J., & Taylor, R. D. (2006). A "Grand Challenge": Measuring Information Societies. The Information Society, 22(5), 261–267. http://doi.org/10.1080/01972240600903904

OECD. (1999). Communications Outlook 1999.

OECD. (2000). Information Technology Outlook 2000.

OECD. (2001). Communications Outlook 2001.

OECD. (2002). Information Technology Outlook 2002.

OECD. (2003). Communications Outlook 2003.

OECD. (2004). Information Technology Outlook 2004 (Information Technology Outlook). OECD Publishing. Retrieved from http://www.oecd-ilibrary.org/science-and-technology/information-technology-outlook-2004_it_outlook-2004-en

OECD. (2005). Communications Outlook 2005.

OECD. (2006). Information Technology Outlook 2006 (Information Technology Outlook). OECD Publishing. Retrieved from http://www.oecd-ilibrary.org/science-and-technology/oecd-information-technology-outlook-2006_it_outlook-2006-en

OECD. (2007). Communications Outlook 2007.

OECD. (2008). Information Technology Outlook 2008 (Information Technology Outlook). OECD Publishing. Retrieved from http://www.oecd-ilibrary.org/science-and-technology/oecd-information-technology-outlook-2008_it_outlook-2008-en

OECD. (2009). Communications Outlook 2009 (OECD Communications Outlook). OECD Publishing. Retrieved from http://www.oecd-ilibrary.org/science-and-technology/oecd-communications-outlook-2009_comms_outlook-2009-en

OECD. (2010). Information Technology Outlook 2010. OECD Publishing. http://doi.org/10.1787/it_outlook-2010-en

OECD. (2011a). OECD Communications Outlook 2011. Paris: OECD Publishing. Retrieved from http://dwmw.files.wordpress.com/2011/06/oecd-commoutlook-2011.pdf

OECD. (2011b). OECD Guide to Measuring the Information Society 2011. OECD Publishing. http://doi.org/10.1787/9789264113541-en

OECD. (2012a). OECD Economic Surveys: Luxembourg 2012. Paris, Paris: OECD Publishing. http://doi.org/http://dx.doi.org/10.1787/eco_surveys-lux-2015-en

OECD. (2012b). OECD Internet Economy Outlook 2012. OECD Publishing. http://doi.org/10.1787/9789264086463-en

OECD. (2013). Communications Outlook 2013 (OECD Communications Outlook). OECD Publishing. Retrieved from http://www.oecd-ilibrary.org/science-and-technology/oecd-communications-outlook-2013_comms_outlook-2013-en

Partnership on measuring ICT for development. (2012). PARTNERSHIP ON MEASURING ICT FOR DEVELOPMENT.

Polynomics. (2012a). Management Summary of the Study Report Polynomics Regulation Index 2012.

Polynomics. (2012b). Manual for the Polynomics Regulation Index 2012 Data Set.

RTR. (2011). Messung von informatorischer und technologischer Reife. Schriftenreihe Der Rundfunk and Telekom Regulierungs GmbH, 1, 156. Retrieved from www.kig.gv.at/Portal.Node/kig/public/Content/files/berichte/NRI.pdf

Sabbagh, K., Pattheeuws, S., Moe, T., Peterson, M., Gillies, S., & Vollmer, C. (2012). Maximizing the Impact of Digitization. Retrieved from www.booz.com

Sandvine. (2013). Global Internet Phenomena Report. Retrieved from www.sandvine.com

Schmitz, F., Drevon, G., & Gerber, P. (2012). La mobilité des frontaliers du Luxembourg : dynamiques et perspectives. LES CAHIERS DU CEPS / INSTEAD. Luxembourg.

Selhofer, H., & Hüsing, T. (2002). THE DIGITAL DIVIDE INDEX – A MEASURE OF SOCIAL INEQUALITIES IN THE ADOPTION OF ICT. In International Telecommunications Society Regional Confernce Copenhagen.

Service des Médias et des Communications. (2013). Luxembourg & ICT - a snapshot. Luxembourg. Retrieved from http://ict.investinluxembourg.lu/ict/luxembourg-and-ict-a-snapshot

SMC. (2009). Plan d'action national en matière de TIC et de haut-débit. Luxembourg.

SMC. (2010). Stratégie nationale pour les réseaux à « ultra-haut » débit. Luxembourg. Retrieved from http://www.mediacom.public.lu/institutions/Institutions_nationales/smc/20100309_ngn/Strategie_nationale_pour_les_reseaux_a_ultra-haut_debit.pdf accessed 15th of January 2013

SMC. (2011). Stratégie nationale en matière de cyber sécurité. Retrieved from http://www.mediacom.public.lu/cybersecurity/Strat__gieCybersecurity_122011.pdf

Statec. (2012a). 2012 Répertoire systématique: Les entreprises luxembourgeoises. Luxembourg.

Statec. (2012b). Annuaire statistique. (STATEC, Ed.) (2013th ed.). Luxembourg. Retrieved from http://www.statistiques.public.lu/fr/publications/series/annuaire-stat-lux/index.html

Statec. (2012c). Luxembourg in Figures. Luxembourg. Retrieved from http://www.statistiques.public.lu/catalogue-publications/luxembourg-en-chiffres/luxembourg-figures.pdf

Tadayoni, R., & Henten, A. (2012). Transition from IPv4 to IPv6. In 23rd European Regional International Telecommunication Society conference; Vienna (pp. 1–19).

Taylor, R. D. (2006). The Nature and Measurement of Information: Two "Grand Challenges" for the field. In 16th Biennial Conference of the International Telecommunications Society. Beijing.

Taylor, R. D., & Cui, J. (2011). Does Happiness Matter ? What do We Want from the National Broadband Plan And How Will We Know if We Get It ? In Telecommunications Policy Research Conference Washington, D.C. (pp. 1–36).

Taylor, R. D., & Zhang, B. (2007). Measuring the Impact of ICT: theories of information and development. In Telecommunications Policy Research Conference, September 26-28, Washington DC (pp. 1–39).

The World Bank. (2008). Measuring knowledge in the world's economies.

The World Bank. (2012a). Knowledge Economy Index ( KEI ) 2012 Rankings.

The World Bank. (2012b). The Little Data Book on Information and Communication Technology 2012 (2012th ed.). World Bank Publications. http://doi.org/10.1596/978-0-8213-6973-9

UN. (2005a). Core ICT Indicators.

UN. (2005b). Measuring ICT: the global status of ICT indicators.

Waverman, L., Dasgupta, K., & Rajala, J. (2011). Connectivity Scorecard 2011. Retrieved from http://www.connectivityscorecard.org/images/uploads/media/TheConnectivityReport2011.pdf

Waverman, L., & Koutroumpis, P. (2011). Benchmarking telecoms regulation – The Telecommunications Regulatory Governance Index (TRGI). Telecommunications Policy, 35(5), 450–468. http://doi.org/10.1016/j.telpol.2011.03.006

World Economic Forum. (2008). The Lisbon Review 2008 Measuring Europe ' s Progress in Reform.

World Economic Forum. (2010). The Lisbon Review 2010 Towards a More Competitive Europe ?

World Summit on the Information Society. (2005). WSIS Thematic Meeting on " Measuring the Information Society ." Geneva-Tunis. Retrieved from http://www.itu.int/wsis/docs2/thematic/unctad/final-conclusions.PDF

Zenhaeusern, P. (2012). Scope of the Polynomics Regulation Index 2012.

Zenhaeusern, P., & Schneider, Y. (2012). Polynomics Telecommunication Regulation Index 2012. In 23rd European Regional International Telecommunication Society conference; Vienna (pp. 1–13). Vienna.

Zenhäusern, P., Schneider, Y., Berner, S., & Vaterlaus, S. (2012). Polynomics Regulation Index 2012. Olten (CH).

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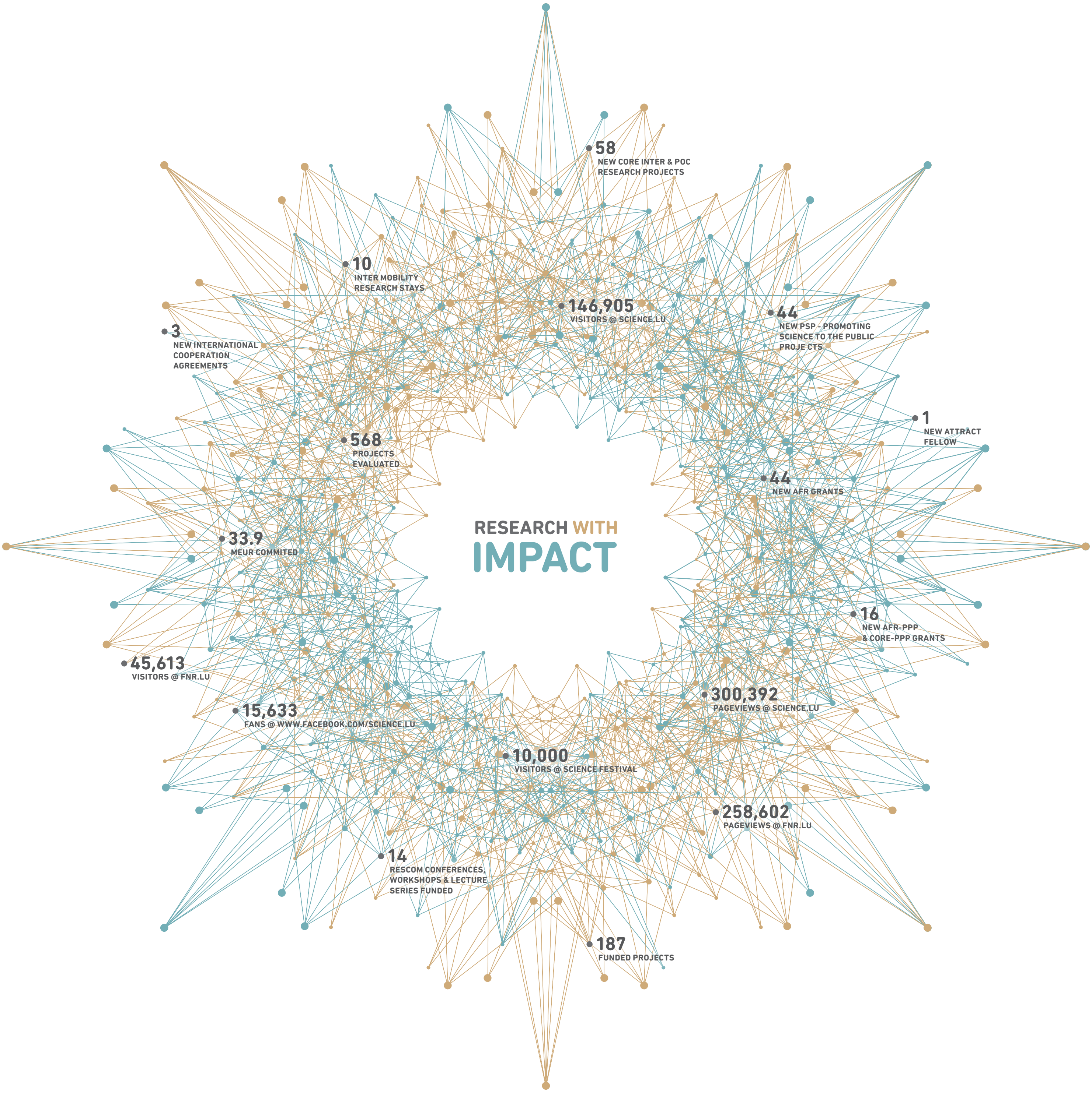


*Key figures:*

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