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Accelerating the Uptake of Smart City Applications through Cloud Computing

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***Abstract*—**Smart cities are high on the political agenda around the globe. However, planning smart cities and deploying applications dealing with the complex problems of the urban environment is a very challenging task that is difficult to be undertaken solely by the cities. We argue that the uptake of smart city strategies is facilitated, first, through the development of smart city application repositories allowing re-use of already developed and tested software, and, second, through cloud computing which disengages city authorities from any resource constraints, technical or financial, and has a higher impact and greater effect at the city level The combination of these two solutions allows city governments and municipalities to select and deploy a large number of applications dedicated to different city functions, which collectively could create a multiplier effect with a greater impact on the urban environment.

***Keywords*—**Smart cities, applications, cloud computing, migration to the cloud, application repositories.

I. Introduction

TODAY'S cities, all over the world, face unprecedented socio-economic and environmental pressures. According to the World Bank, more than 50% of the global population is living in cities, a percentage which is expected to rise to 66% by 2050 [1]. Increased urbanization trends force local and regional governments to shoulder the burden of coping with significant problems such as traffic congestion and environmental pollution, overburdened public services, high unemployment as well as social tensions and crime.

Following the Urban Thinker Campuses and their manifesto: "The City we Need: How we plan, build, and manage our cities today will determine the outcome of our efforts to achieve a sustainable and harmonious development tomorrow. Well-planned cities allow all residents the opportunity to have safe, healthy, and productive lives. Well-designed cities present nations with major opportunities to promote social inclusion, resilience and prosperity" [2]. Yet, planning, managing and developing services for cities are a huge task that is difficult to be addressed solely by city governments [3]. Nowadays, cities have to turn towards digital technologies, empower their citizens through collaborative platforms and harness peoples' creativity, foster new learning processes, utilise open proven solutions and/or outsource services in order to deal efficiently with their problems and achieve their strategic priorities [4]-[6]. In this regard, they are not only able to develop and utilise products and services that are beyond their internal capacity, but they also avoid reinventing the wheel.

Over the last years, cities in the US and Europe have embraced open innovation through the establishment of collaborative and/or competitive communities [7]. Besides, in the growing discourse on smart cities, bottom up initiatives and grassroots efforts based on the participation of heterogeneous actors such as citizens, companies and organisations have been identified as core elements of the urban innovation ecosystem empowering co-creation and collective intelligence through means of democratic innovation [8]. Open data, virtual platforms and digital technologies can be used to achieve open innovation and assist cities to self-organize more efficiently for the benefit of their citizens [9].

A first example of open innovation initiatives through digital means is crowdsourcing ideas from online communities in the sense of giving end-users or citizens, as external sources of innovation, a voice and an active role in addressing specific urban challenges [10]. Since 2010, a growing number of crowdsourcing platforms devoted to civic improvements, such as By the City/For the City, change.org, City Atlas and Big Ideas, have been used for collecting ideas, services or content from a large group of people. Philadelphia, New York and other cities have launched 'Change by Us' to broadcast citizen's ideas, to join or create projects, build teams and find resources turning their ideas into reality. The 'City of Ideas', which is used by Buenos Aires or Medellin in Colombia, enable citizens to contribute with ideas to changing their city. Street Bump is a crowdsourcing project used to collect real time road condition data from drivers, while EVApp is an emergency volunteer smartphone application mobilising professional volunteers to the time between an emergency call and arrival of the emergency services [11]. In fact, crowdsourcing includes a much larger number of practices including the development of open-source software or multiple content aggregators, new big-data analysis applications, citizen science initiatives and social mapping [12], [13].

Second is the establishment of competition community ecosystems through the organisation of civic hackathons and application development contests, such as the Boston hackathon, smartcitieshack or New York BigApps Competition. A hackathon is an event in which computer

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programmers and others involved in software development collaborate intensively over a short period of time (typically for one or two days) to develop a new software application that meets the challenge posed by the organisers [14]. Such competitions have emerged as an effective approach to encourage innovation through digital technologies and innovate under conditions of austerity. Civic hackathons leverage government open data to develop applications that citizens may find useful. According to [15], the 2008 Apps for Democracy contest organised in Washington DC for a period of one month, led to the development of 47 smartphone apps representing a value of over $2,300,000 in software with a prize of only $50,000.

Third is the creation of collaborative communities of city web services which offer repositories of applications that can be shared between cities [7]. A popular initiative is Code for America, an organisation established in 2011 that taps on volunteer programmers, called as 'fellows', to work with an assigned city for a specific period of time in order to develop applications that improve aspects of their citizens' lives. Such collaboration initiatives allow cities to redeploy each other's apps and work together to tackle common policy challenges. They also promote social innovation through civic accelerators. The enormous success of Code for America has also been transferred to Europe through projects such as Commons for Europe, open cities and Code for Europe.

All these initiatives bring significant benefits to municipal authorities such as reduced development costs due to the utilisation of external sources, the engagement of citizens and increased transparency, as well as the offering of improved municipal services and so on.

Despite the number of applications developed and offered through different repositories (e.g. Github, Apps for Barcelona etc.), we identify the need for more targeted and - at the same time - more integrated solutions, i.e. repositories exclusively focused on smart cities, organizing software in different domains which are associated to urban problems. We also argue that such repositories combined with cloud computing can facilitate the uptake of smart city services, by disengaging city authorities from any resource constrains, technical or financial, but also by allowing them to use a large number of applications which altogether create a synergetic approach with a higher impact on the urban environment.

The paper is organized in four parts. The introduction, after a review of the effect of open innovation on the creation of smart city applications, outlines the intended research outcomes. Section II presents the advantages of cloud computing for smart cities. Section III is dedicated towards the migration of smart city applications to the cloud, first, by introducing ICOS, an Intelligent City Software and Solutions repository aiming to facilitate re-use of software for smart cities and, second, by describing a experiment of public services migration to the cloud within the framework of Storm Clouds Project. Section IV discusses some general guidelines with regards to migration of city services to the cloud.

II. Advantages of Cloud Computing for Smart Cities

Cloud computing has emerged during the last years as a disruptive model with the ability to transform IT organizations to be more responsive and agile than ever before. This model represents a fundamental change in the way that information technology, hardware and software are invented, developed, deployed, scaled, updated, maintained and purchased [16]. Cloud computing serves as an enormous step towards delivering computing as a utility (like traditional utilities such as water, electricity and telephone) [17] by changing the traditional access model, where data and applications are fully contained in the same physical location (the users' computers), to a new one, where the users access their data and applications outside their own computing environment through the Internet.

The US Government's National Institute of Standards and Technology (NIST) defines cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [18], while the IT research and advisory company Gartner, uses a simplified definition and defines cloud computing "as a style of computing in which scalable and elastic IT-enabled capabilities are delivered as a service using Internet technologies" [19]. A common analogy to understand cloud computing is renting versus buying. Actually, someone rents IT capacity (computing power, disc space, applications, etc.) from a cloud service provider and uses it over the Internet; instead of buying their own IT requirements. Moreover, the user pays only for the resources used.

Cloud computing promises economic benefits, speed, agility, flexibility, rapid elasticity and more innovation; the motivations of the organisations for the migration of their applications to the cloud are closely related to the following four key cloud computing characteristics:

- On-demand self-service as needed automatically without requiring human interaction with the cloud provider.
- Broad network access through heterogeneous devices (e.g., mobile phones, tablets, laptops, and workstations).
- Rapid elasticity in the sense of rapidly scaling up or down the IT infrastructure commensurate with demand.
- Measured service, leading to a transparent relationship between the consumer and provider of the cloud service.

The above-mentioned characteristics create a highly efficient, scalable and elastic computing environment, which gives city authorities and municipalities everywhere the opportunity to collect, store, analyse and manage enormous amounts of data coming from heterogeneous sources (sensors, smartphones, household appliances etc.) in the urban environment more effectively and at a lower cost than in-house solutions [20]. Furthermore, as the cloud providers apply the latest security techniques, as soon as they become available, cloud computing offers the most secure infrastructure, making it the best solution for implementing new smart city applications [21]. Nonetheless, cloud-based smart city services "need to work with legacy on-premise systems and across multiple verticals if they are to deliver the full benefits that smart city implementation can bring" [21].

III. Migrating Smart City Applications to the Cloud

A. Software Applications for Smart Cities: The ICOS Repository

The technology stack of smart cities includes a series of layers that enable communication among actors of the urban system, gathering data from multiple sources (sensors, users, and public authorities), compiling data and processes over software applications, and developing e-services that address city challenges and goals. This multi-layer architecture has been described as:

– "a pervasive overlay of information and communication technology connecting things, organizations, and people" [22];
– an urban operating system that provides "a unified sensor data acquisition, real-time control, historical database, analytics engine, and application hosting platform for urban environments, or – deployed in a public cloud – for remote devices with sensing and actuation capabilities" [23];
– a "set of technological requisites for smart city [that] comprises network equipment (fibre optic channels and Wi-Fi networks), public access points (wireless hotpots, kiosks), and service oriented information systems" [24]; and,
– as consisting of four concentric rings: at the centre are the broadband networks, wired and wireless infrastructure and communication protocols; then comes a ring of web technologies that enable data protection, processing, exploration, visualisation and analytics; the third ring is composed of applications for information and web-based collaboration in different domains of the city; and the last and outer ring is composed of e-services as a few applications are offered on a regular basis as a service [3].

Software applications are core component of this digital edifice and form a discrete layer of the smart city technology stack. They work as integrators of heterogeneous ICT hardware, data, user engagement and urban processes. Applications are directly targeting urban problems and challenges. The range of the latter is more or less defined in the literature [25]-[27] and can be classified under the four constituting subsystems of any city: *economy, living, infrastructure,* and *government* (see Table I).

Developing applications and solutions to address these problems, city authorities and organisations managing utilities should avoid both unnecessary spending and technology lock-in. 'Share more - Develop less' is a culture to adopt, share applications between cities, create alliances, offer applications for free to other cities, use existing software, re-use software.

As the smart city paradigm progresses, more and more applications become available and city authorities get insights from other cities and become aware of software that can use in response to city challenges and needs. Large scale software repositories, such as GitHub [28], SourceForge [29], Bitbucket [30] and other, are important sources of software for cities and pillars for the dissemination of the smart city paradigm. The same holds for smaller and dedicated repositories of smart city solutions, such as the Code for America [31], Apps for Barcelona [32] or applications produced in the framework of hackathons and competitions [33] and research projects [34]. Open source licenses and modular software architectures facilitate the uptake of smart city solutions. Both public repositories and open source software are compatible to the culture of cities as non-profit institutions. Sharing and replicability of solutions are also considered as maturity indexes of smart city development, especially the deployment of repeatable standard processes, the adoption of service oriented architecture, and use of open platforms across administrative departments [35].

TABLE I
MOST RENOWNED URBAN PROBLEMS

Economy and growth	***Governance***
Decline of manufacturing / industry	Transparency of decisions
Urban decay / Inner city decline	Corruption of local government
Disinvestment / Capital flight	Good government
City districts job loss	Red tape
Fiscal crisis	Technological hazards
Unemployment	Natural hazards
People flight, gentrification	Terrorism
Poverty	
Living conditions – Quality of life	***Urban infrastructure and utilities***
Lack of housing / Rent squeeze	Traffic congestion
Homelessness	Traffic pollution / Noise pollution
Slams and squatter areas	Parking availability
Crowding / high density areas	Fatal accidents
Crime / violence / aggression	Clean water provision
Vandalism	Waste disposal
Safety / security	Storm water and floating relief
Public education and schools	Shortage of electric power
Poor public health	Low Internet connectivity
Poor social care	Aging infrastructure
Air pollution	
Pollution of land	
Areas of environmental degradation	
Natural habitats / ecosystems at risk	

In this line of thinking and with the aim to facilitate the re-use of software for smart cities, we created the *ICOS (Intelligent City Software and Solutions) repository* [36]. It supports a community offering software applications for intelligent cities/smart cities, by showcasing existing projects, providing a forum for discussion, and guiding developers' groups in applications' creation, contribution, and release. ICOS is a meta-repository. It describes software applications for smart cities, users can submit applications, and links are provided to official websites and the GitHub to download the software. Currently, ICOS hosts 83 applications, classified by city function they serve, software function, and license (Table II). These were selected from various sources, such as the Government Technology Magazine, the Code for America, the Opensource.com initiative, the Open City Apps, the LinkedIn Open Source Solutions for your Smart City, and other.

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TABLE II
SOFTWARE APPLICATIONS IN THE ICOS REPOSITORY

City function	Number	Percent
Innovation economy	9	10.84
Living in the city - Quality of Life	14	16.87
City infrastructure and utilities	10	12.05
City governance	24	28.92
Generic	26	31.32
Total	83	100.00
Software function		
Citizen aggregation	22	22.22
City decision-making / city planning	18	18.18
City district improvement	2	2.02
City sector improvement	4	4.04
City infrastructure / network optimisation	14	14.14
City representation	4	4.04
City services	28	28.29
Location-based services	7	7.07
Total	99	100.00
Software license		
Open source	69	83.13
Proprietary	14	16.87
Total	83	100.00

Applications within each city function category indicate the kind of problems that applications focus on. On the other hand, the function of software indicates how the application works with city entities, such as citizens, city districts and sectors, city utilities and what type of functionality it offers. Because the categories of urban problems (Table I) and the categories of applications (Table II) are the same, we can identify the kind of applications that are used per category of urban problems and the type of function or process they actualise to these problems.

In the "innovation economy" category, applications deal mainly with marketplaces (e-commerce, CRM) and crowdfunding. They address economic growth challenges in a proactive rather than defensive way, creating opportunities for business expansion and funding for new businesses. Applications offer mainly with citizens' aggregation, collaboration to problem-solving, and access to services (e-commerce). Location-based services are meaningful when services rely on city assets, monuments and points of interest. All software licenses in this category are open source.

Applications concerning "living in the city" deal with three out of four types of urban problems in this category: crime prevention and safety; public health and social care; and monitoring air quality and the environment. Most frequent software functionality is citizen aggregation and the added value of applications consists in the mobilisation of citizens undertaking common action towards a challenge. But, other types of functionality also appear, such as support to decision making, improvement of city districts, sectors, and utilities. All licenses, except one, are open source. As expected, applications in the domain of "city infrastructure and utilities" focus on transport, energy, water and waste. The association to urban problems is clear and direct. The main functionality they offer is optimisation of the respective city infrastructure and saving of resources. Applications divide equally to open source and proprietary licenses.

Finally, applications in the field of "city governance" deal with problems of transparency and good government. Technological and natural hazards or fight against terrorism demand more complex hardware – software systems and solutions. The functionality of applications consists in aggregating citizen requests, supporting decision making and city planning, and offering administration services to citizens.

A clear conclusion from the ICOS repository is that a variety of urban problems can be addressed with smart city applications. The 83 applications included in the repository do not cover all problem areas. Their impact is not always satisfactory and can be substantially improved with better design of ontologies [37]. Most applications have narrow ontology and eventually limited impact with respect to the complexity of the urban system. It becomes necessary to combine groups of applications providing an operating solution. For instance, the fight against vandalism requires the synergy between citizen reporting, citizen consultation, and crowdfunding applications, which together raise awareness, define solutions and gather resources for their implementation. This synergetic approach requires a quick uptake of a large number applications by city authorities, standardisation and simplification in their customisation and use. These goals can substantially be facilitated and accelerated through cloud computing.

B. Uptaking Smart City Applications through Cloud Computing

This section explains a methodology for the migration of smart city applications to the cloud using the experience gained from the Storm Clouds Project, an EU co-funded CIP project [38], which aimed to accelerate the pace at which Public Authorities move to cloud computing. By using this approach, public authorities can take full advantage of the cloud computing model and provide citizens with highly reliable, as well as innovative services quickly, despite resource constraints. This methodology emerged from the migration of seven Smart City applications, which cover a variety of city functions (Table III), into the cloud in four European Cities. The term *cloudification* is used to describe "the conversion and/or migration of data and application programs in order to make use of cloud computing" [39].

The main assets of the project are the following:

- *Storm Clouds Platform (SCP).* The platform provides the cloud environment, which can host Smart City Applications. It is an advanced, customizable, distributed IaaS cloud architecture based on open source technologies.
- *Portfolio of professional services* offered on top of the reference IaaS infrastructure ensuring a high level of automation, security and data protection, including monitoring of the resources (CPU load, disk space occupation, network traffic, number of processes, etc.) used by the platform's services or by the applications.
- *Portfolio of Smart City Services*. A consolidated and

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interoperable open-source cloud-based services portfolio running on top of the open source cloud infrastructure (Table III).

- *Roadmap for the migration of public services into the Cloud.* The roadmap consists of guidelines that help Public Authorities to address the technical and business challenges in the adoption of cloud computing.
- *Best practices for cloud-based public services deployment.* The best practices include software techniques and methodological approaches, which facilitate the adoption of Cloud services in the Public Sector.
- *Business models for the scalability and sustainability of the project's assets.* The business models cover the exploitation of the SCP and Smart City services, as well as the viability of the already cloudified services in the project's pilots.

The methodology, which is presented in Fig. 1, envisages the migration of Smart City applications into the cloud as a process with six overlapping phases.

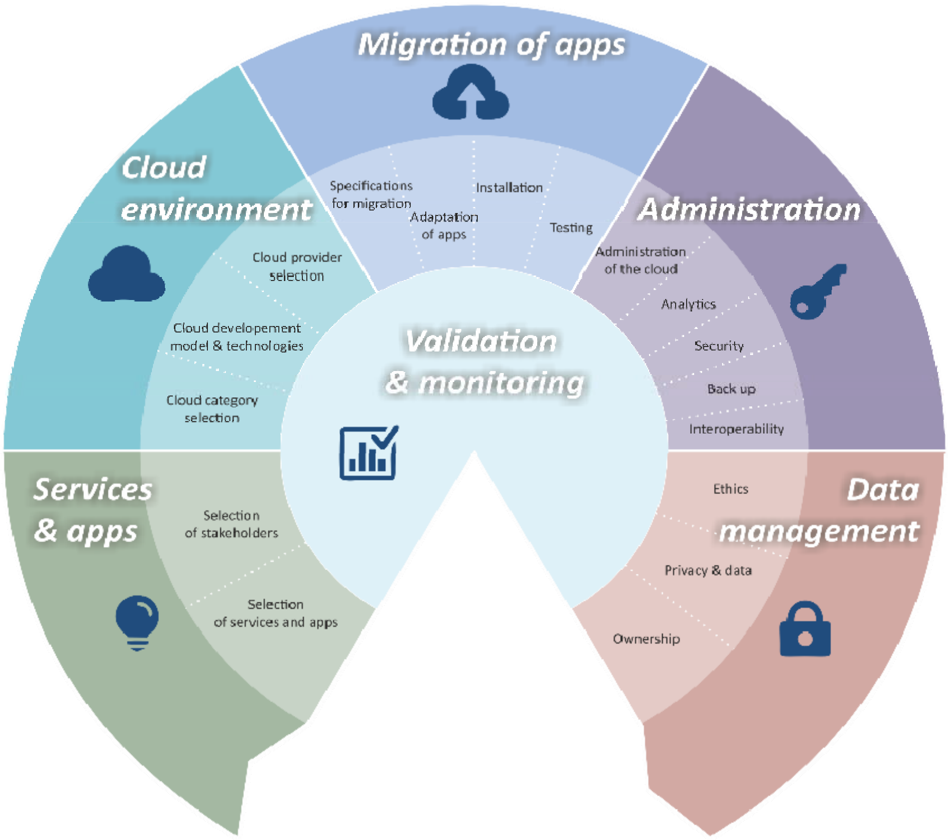

Fig. 1 The STORM CLOUDS approach on migration of Smart City applications to the cloud

Phase 1 deals with *the selection of the most suitable applications for deployment into the cloud environment.* Here, a user driven open innovation methodology [40], [41] was adopted, in order to select the applications that would migrate to the cloud. During this procedure, the involvement of a number of stakeholders (derived from citizens, public authorities, local enterprises and organisations) was essential, not only as a methodological requirement but also because the participation of the parties concerned' would produce helpful feedback for the overall process to be closer to citizens and public employees. The selected applications were good candidates for cloudification, as they expected to take full advantage of the elasticity of cloud computing. In particular, some of them (VCM, City Branding, Live the City and Public Failure Reporting System) were used initially by a small number of citizens and therefore had low workloads, but it was expected to be used by the majority of city residents and in that case would have high workloads. The remaining applications (CloudFunding, Location Plans and Have your Say) had high workloads and occasionally required significant computing resources (i.e. when new plans are set for discussion, new crowdfunding campaigns are available, etc.).

Phase 2 includes *the creation of the cloud environment that will host the applications.* The Storm Clouds Platform is built upon widely accepted open source technologies, so it will not lock the organisations that use it into a proprietary ecosystem. Moreover, its architecture is a baseline for future extensions and modifications with the objective to allow developers to improve the way functions are implemented or to add new features not currently available. The SCP enhances the IaaS solution with two modules (Data Service layer and Access layer) that provide the high-availability and scalability features in a way that they are transparent to the application owners. This approach offers great flexibility as it does not require architectural changes to the applications but also keeps the deployment complexity low because the application owner "leverages" the availability and scalability features of the platform. Cities have at their disposal both "scale-up" architecture for traditional applications (Fig. 2) and "scale-out" architecture for cloud-ready applications (Fig. 3).

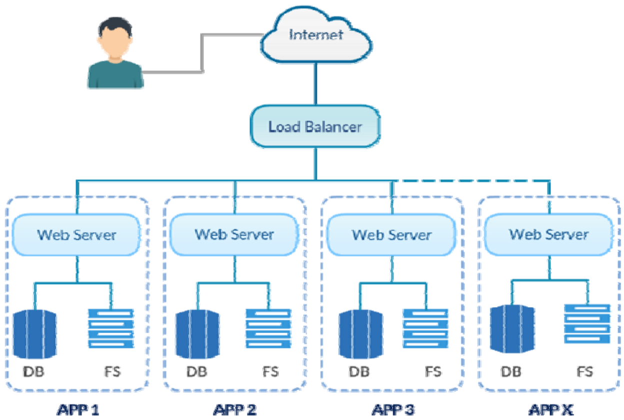

Fig. 2 Logic diagram of SCP's "scale-up" architecture

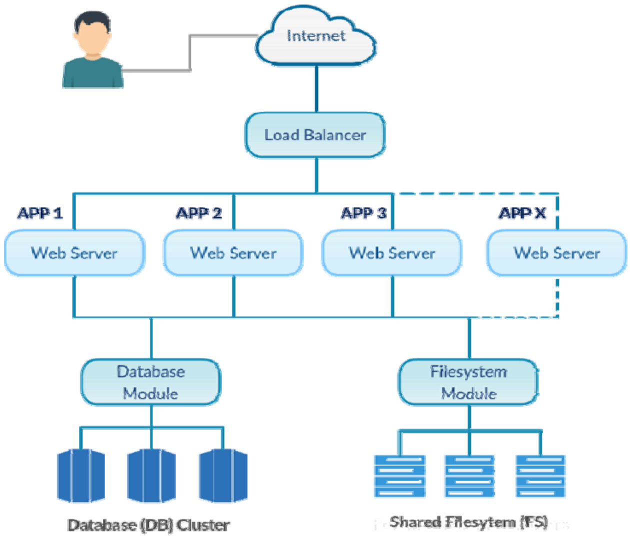

Fig. 3 Logic diagram of SCP's "scale-up" architecture

The SCP also supports public, private, as well as hybrid cloud deployment models.

Phase 3 includes *the migration of the applications into the cloud*. The migration can be described as a multi-phase process, which included all the necessary steps that ensured the smooth deployment of the selected smart city applications to the SCP. The process started with the assessment of each application regarding its readiness for the new cloud environment, its architecture and its functional and non-functional requirements. This analysis leaded to some necessary improvements in order the application to be optimised for the SCP. Afterwards, the code and data deployed in the platform's application and data service layers, respectively. The process was completed with the validation that the application was fully operational in the new cloud environment. The cloud encourages automation because the infrastructure is programmable. To ensure a high level of automation along with accuracy in the migration of the applications to the cloud, a set of tools and procedures have been designed and developed. These tools allow interested cities to automatically deploy the selected applications from the cloud-based service portfolio, as well as the municipalities to re-deploy their services in another instance of SCP.

TABLE III
STORM CLOUDS PORTFOLIO OF SMART CITY APPLICATIONS

City Function	Application	Description
Innovation economy	Virtual City Market (VCM)	Enables the creation of a community driven marketplace that promotes the city's local shops and introduces new collaboration schemes among retailers.
	CloudFunding	Supports local communities to collect money for social & charitable purposes.
	City Branding	Promotes the identity of a city in different target groups using interactive maps, 360° panoramas, video & images.
City governance	Public Failure Reporting System	Enables citizens to report, via web or mobile, non-emergency local problems to City Authorities.
	Location Plans	Supports the preparation of location plans with the active involvement of the citizens.
	Have your Say	Supports bottom-up decisions, by enabling Municipalities to ask the citizens' opinion about the future city plan, theme or issue.
Living in the city	Live the City	Enables citizens to share information about leisure events in the city, map located and classified according to its cost, type and place.

Phase 4 is related with *the administration of the Cloud environment*. The SCP includes features that both the platform administrator and the application owners can use for managing, monitoring and administering the platform's components as well as the applications running in the cloud. The actions that a user can perform, depend on his/her role: the platform administrator has full control on all the components deployed in the cloud, while the application owners have full control of their applications and can perform only some actions on the platform components. For instance, application owners have full control over databases and shared volumes used by their applications, but they do not have any control on databases and shared volumes used by other application owners.

The phase 5 deals with *the data management and security of the solution*. In order to achieve a clear understanding of the security requirements of both the SCP and the smart city applications, a number of penetration testing tools were used to facilitate the security testing procedure [42]. The security testing identified a number of critical security issues resulting in applications' modifications in order to address them. To enhance the authentication process, all applications have been updated to support session expiration, thus minimising the time available to an attacker who uses a valid session identifier. In order to balance between security and usability, applications have properly selected the timeout values, allowing users to complete their operations without frequent session expirations. The acquisition of an HTTPS certificate

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was necessary for the protection of data in motion for smart city applications. Another mechanism that has been implemented for data protection is the automatic backup. The aim of the backup procedure is to keep data from being lost due to intentional or unintentional access.

The final phase is devoted to *the monitoring and validation of the whole process*, which targets the business aspects of the applications rather than the technological ones. This approach is more holistic as the successful migration in business terms implies the success of the technical one. The process consists of three different steps: i) identifying the aspects to monitor and the specific indicators or criteria (depending on the task), ii) information gathering throughout the entire process of cloudification, and iii) analysis of the usage and acceptance of the new applications and/or variations on the usage patterns. The main indicators that usually apply to this process are indicators monitoring the supply side of the service, indicators monitoring the demand side of the service, indicators related to dissemination, indicators related to validation of the service, and finally, indicators showing the financial benefits of migrating an application to the cloud.

The described experiment helped four European Cities (i.e. Agueda, Miscolc, Thessaloniki and Valladolid) to understand how to successfully deploy smart city applications on the cloud. In addition, the outputs of the project provide guidance and tools to public authorities (both decision makers and IT staff) for considering and executing the migration of their applications to a cloud computing environment.

IV. Discussion And Conclusions

The experiment described in the previous section reveals a number of generally accepted guidelines that ensure the successful migration of applications to the cloud.

Prioritisation of the applications that should move to the cloud – As public authorities start migrating their applications to the cloud, it is important to determine which applications fit better into this environment. The best candidates are applications that take advantage of the cloud's ability to automate the dynamic of resources to match the current demand. Moreover, the rapid elasticity combined with the pay-by-usage characteristic of the cloud can lead to significant financial savings [43]. Table IV presents some of the characteristics of both; the more suitable candidates for the cloud and the less suitable candidates. The Smart City Services included in the STORM CLOUDS portfolio are examples of good candidates for the cloud.

Selection of the right Cloud Service category – Public Authorities should take into account the different service categories of cloud computing (i.e. Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS) or Infrastructure-as-a-Service (IaaS)). Fig. 4 depicts the various control responsibilities that cloud customers and providers have in IaaS, PaaS, and SaaS environments [44].

TABLE IV
APPLICATION CANDIDATES FOR MIGRATION TO CLOUD (SOURCE [35])

More Suitable Candidates	Less Suitable Candidates
– Applications that are designed to spread their workload across multiple servers. – Applications that run occasionally but require significant computing resources when they run. – Applications with unpredictable or cyclical usage patterns. – Service Oriented Architecture (SOA) Applications.	– Applications that include extremely sensitive data. – Performance-sensitive applications. – Applications that require frequent and/or voluminous transactions against an on-premises database that cannot be migrated to a cloud environment. – Applications that run on legacy platforms.

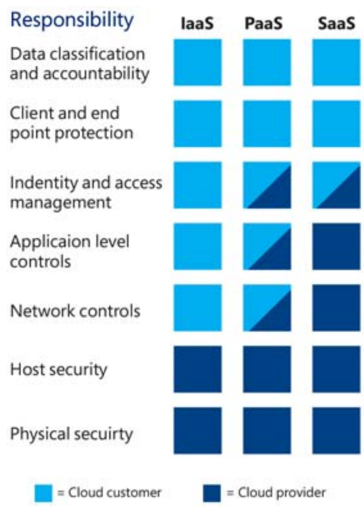

Fig. 4 Considerations for choosing a Cloud Service category (Source [44])

As SaaS is not applied when Public Authorities want to deploy their existing applications to a Cloud Environment, they have to select between IaaS and PaaS. On the one hand, the IaaS offers excellent flexibility, as it does not require architectural changes to the applications, and full control of the resources used for the deployment. However, it increases the deployment complexity, as the application owners must take care of installing and configuring all the components for high availability and scalability. On the other hand, the PaaS "hides" the complexity of the underlying infrastructure and allows developers to deploy their web applications to the cloud without having to take care of the infrastructure. However, the applications may require significant changes to comply with the PaaS principles and take full advantage of high availability and scalability features. In particular, as application instances are ephemeral and can be started, stopped or fail at any time, they must be stateless and share nothing. All persistent data must go to external services (e.g. databases, file storage, message queues, and caches) [45]. The SCP's "scale-out" architecture enhances the IaaS solution by implementing the Data Service layer and Access layer, which handle the data and the HTTP traffic, respectively.

Selection of the right Cloud Deployment Model – Public Authorities should take into account the different Deployment Models of Cloud Computing (i.e. Private, Public or Hybrid Cloud). The Table V summarises the pros and cons of the different deployment models [46], [47].

TABLE V
PROS AND CONS OF PRIVATE, PUBLIC AND HYBRID CLOUD DEPLOYMENT MODELS (SOURCE [46], [47])

Option	Pros	Cons
Private Cloud	– More control and reliability – Customizable	– Requires IT expertise – Costlier
Public Cloud	– Ease of management – Ease of deployment – Flexible	– Can be unreliable – Less secure
Hybrid Cloud	– Flexible and scalable – Cost effective	– Complexity of management – Requires IT expertise

In short, when choosing a specific cloud deployment model, it comes down to a series of trade-offs related to cost, management and security. While public clouds may be the best option for small organisation from a cost perspective, organizations that require more control and/or security may opt for a private or hybrid cloud.

Embrace the Power of Open Technologies: Platforms composed of open technologies provide the freedom to change environments and deliver a robust and secure experience extending the existing IT to the cloud. They enable customers to do more work with less infrastructure, deliver a broader range of services, incorporate new technologies and boost greater innovation around the cloud [48]. The majority of existing cloud offerings is implemented in proprietary and highly standardised form. What presents advantages for the provider – technological knowledge, economies of scale, etc. – creates troubles and frustration for the customer. Users complain of “vendor lock-in”, where they are dependent on a given vendor with no freedom of choice. Adopting an open cloud by design means, on the one hand, that the cloud infrastructure is built upon open technologies such as OpenStack and Cloud Foundry, and on the other hand, that the cloud provider facilitates the creation of an open ecosystem, which allows independent vendors and service providers to offer their solutions. This open approach enhances the competition between the cloud providers, enabling customers to maximise the benefits of the cloud solutions. [49].

Plan Carefully and Automate the Migration: Comprehensive planning, driven by a disciplined migration process will contribute greatly to a successful redeployment of the applications to a new cloud environment as they reduce the implementation risk and speed-up the migration process. During the migration process the following technical considerations must be taken into account:

– The creation of a detailed inventory of the current application portfolio really helps in terms of understanding the scope of a migration effort.
– A security audit of the application and its data is vital.
– Temporary subsystems can be established to facilitate migrations.
– Standardization and automation can help reduce the risk of migration errors.
– The creation of migration tools, which ensure a high level of automation along with accuracy in migration can result in less time spent in migration and testing.

Use the Right Tools to Manage and Monitor the Cloud Environment: Cloud Computing imposes new concepts and challenges for the role of monitoring and management of the Cloud environment and smart city applications. One of the characteristics of the Cloud, which facilitates the agile deployment of the applications, is the fact that administrators do not have to master the art of capacity planning because they have the ability to create an automated elastic environment [50]. If they can understand, monitor, examine and observe the applications’ load and traffic patterns, they will be able to manage this elastic environment more effectively. Moreover, by measuring and monitoring the performance of the cloud applications, the application developers will have the opportunity to identify proactively any performance issues and to diagnose the root causes, so they take appropriate actions. The “pay for what you use” approach of the Cloud, leads application owners to strive to optimize the system whatever possible. Even a small optimization might result in thousands of Euros of savings.

Focus on Security, Data Protection and users’ Privacy: Cloud Computing security is an evolving sub-domain of information security and refers to a broad set of policies, technologies, and controls deployed to protect data, applications, and the associated infrastructure [50]. In general, the security concerns associated with cloud computing can be classified into two categories: (a) issues that must be addressed by cloud service providers and (b) issues that must be addressed by cloud consumers [51]. Providers must ensure that their infrastructure is secure and clients’ data and applications are protected; customers, on the other hand, must ensure that their provider has taken appropriate security measures to protect their information. The security expectations and obligations of both supplier and user are described in Service Level Agreements (SLAs) [42].

In order to create and implement an appropriate data protection process that will safeguard the users' valuable information from corruption or loss, organisations must understand the specific security requirements and the regulations that apply to each application that they want to move to the cloud. To achieve this, they should perform data protection audits to identify issues that are unique to that application and are related not only to technical problems (i.e. access control, integrity, availability, etc.), but also to governance, and compliance matters. This approach will reveal how the migration and redeployment of an application to the cloud could impact the application's security processes [52].

Privacy is understood as the right of a person to have his personal data properly secured. Moreover, it is related with the ability of a person to control, edit, manage and delete information about them and to decide how and to what extent such information is communicated to others [53]. Cloud services have the capability to reduce the technical barriers to information sharing by providing new ways for organisations to share data. For example, by using a third-party SaaS single sign-on solution for creating user accounts, Public Authorities or Agencies can easily share citizens' private data between them. However, public bodies must guarantee that they properly handle access to personal information and comply with the obligations deriving from the European or National Privacy Legislations [54].

The guidelines for the successful migration of applications to the cloud combined with the open repositories of smart city applications can accelerate the uptake of smart city applications by public authorities. In addition, specialised platform such as the STORM CLOUDS platform further facilitate the process.

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