THE INCREMENTAL VALUE OF SMART BUILDINGS UPON EFFECTIVE RENTS AND TRANSACTION PRICES

by

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Submitted to the Program in Real Estate Development in Conjunction with the Center for Real Estate in Partial Fulfillment of the Requirements for the Degree of Master of Science in Real Estate Development

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Abstract

Smart buildings have grown from an increase in digital technologies that can sense, recognize and verify the experiences of the building and its inhabitants. Nascent literature has identified what it means to be considered smart. Buildings must respond to all three components of systems, performance, and service and has to have the following components: a) Smartness and technology awareness, b) economic and cost efficiency, c) personal and social sensitivity and d) environmental responsiveness. Yet, it is unclear whether these systems have any value to the users or its owners. This thesis studies the economic impact of Smart, Connected and Green buildings upon rents and transaction prices. Using numerous data sources, we identify buildings that offer at least one so-called "smart" amenity and link them with the building's achieved rent and transactions prices as well as to other so-called "innovation" amenties, like greenness and or fiber-lit connectivity. Results documented in this study suggest that buildings that offer a more integral solution (i.e. buildings that are Smart, Connected and Green) have a premium in both rents and transaction prices over similar office products. While products that offer a more desintegrated solution have a smaller premium or even no incremental value premium, with the exception of green only buildings that offers a premium by themselves. This study contributes to the vast literature on real estate innovation but explores particulary the recent commercial office products that are Smart Buildings.

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Introduction

The workplace has been continuously changing for the last three decades from open to closed floor plans, from hoteling to assign sitting strategies; companies have been debating about what is the most productive scheme of work. However, most importantly in the last decade, the entry of millennials in the job market and the fast pace of technological discoveries are starting to be a disruptive force for the real estate market, and increasingly for office products.

On the one hand, speculation about the decreasing rate of the space per employee ratio and the rise of high-performance working spaces has started to create questions about the future of the workplace and office buildings.

On the other hand, the rise of the Internet of Things, robotics, machine learning and automation connected to the new possibilities of interaction between the physical and virtual world has captivated the imagination of many. The MIT Media Lab has been a pioneer in the exploration of how these technologies can be part of our daily life and improve it. A part of this change has focused on making buildings intelligent, self-sensing and soothing, the rise of so-called "smart" buildings.

Nowadays, to be considered smart, buildings must "respond to all three components of systems, performances, and services and has to have the following components: a) Smartness and technology awareness, b) economic and cost efficiency, c) personal and social sensitivity and d) environmental responsiveness" (Ghaffarianhoseini et al., 2015).

Many efforts have been made to classify and demonstrate the operational performance of the new technology systems that make our buildings smarter. However, relatively little information has been gathered on the possible impact that Smart Buildings may have on rent and transaction premiums or how institutional investors are incorporating these technologies into their portfolios in the first place. To measure the impact of smart buildings on the economic performance of real estate, firstly, we developed a classification of smart building characteristics. Secondly, we identified buildings with these characteristics in the most competitive office market: New York City. Finally, we measured whether there is an economically significant deviation in rents or transaction prices in deploying smart building technologies in office real estate products.

The results of the analysis suggest that Smart Buildings, those who mix Smart features, a connected infrastructure, and a green strategy, offer a premium on net rents per square feet and transaction prices per net square feet. We document that those developers or owners that are offering a more integrated solution in their buildings (i.e., Smart, Connected and Green buildings) have achieved a considerable 37 percent premium in rents and 44 percent premium in transaction prices, relative to non-Smart, Connected or Green buildings in the same neighborhood and over the same period of 2013 to 2017.

These results are significant because they show that an intelligent innovation is rewarded with premium rents and transaction prices. They also show, that the hype of smart buildings is more than just a speculation and occupiers are willing to pay for spaces that offer solutions that go beyond just green, although green is still one of the most important features that tenants value the most.

The paper is divided into four sections. The first section will explore which drivers are pushing the changes in the workplace. For this purpose, literature research of industry experts will be the basis of this assessment. The second section will present an analysis of how Office Buildings are physically affected, what are the new functionalities that buildings can have and what role does technology play. In the third section, we will assess if there is early evidence of rents and transaction premiums produced by smart buildings. Finally, we will discuss the diffusion of smart building technologies in office real estate and its impact on the financial performance of buildings.

Technology innovation and the office market

1. The market players: Different values for different stakeholders

Since the beginning of humankind, we began building structures for sheltering from external conditions and animals that surround us. Huts and caves were the first real estate assets, which primary function was to provide shelter for their first inhabitants. Soon, the primitive functionality of this shelters started to evolve, and other elements appeared.

It is easy for us to imagine some of the steps that people took to improve this basic structures. They started by adding a stone paving or a wood-platform to maintain their feets dry. Later on, they added a primitive chimney that allowed them to have an internal fireplace that provides light and heat, and so on.

Each improvement made by our ancestors was at first a novelty, technology that added new functionalities to our evolving structures, but soon after this innovation became the standard practice and then, finally, the acceptable minimum as following improvements superseded it. What was considered an innovation for one generation might be considered as inferior a generation or two later.

With more and more innovations, buildings became a more permanent structure, which could survive and serve more than one generation of people. Soon enough, humans started to inherit properties as well as selling them. Properties became not only places to live and work but also assets that people possessed.

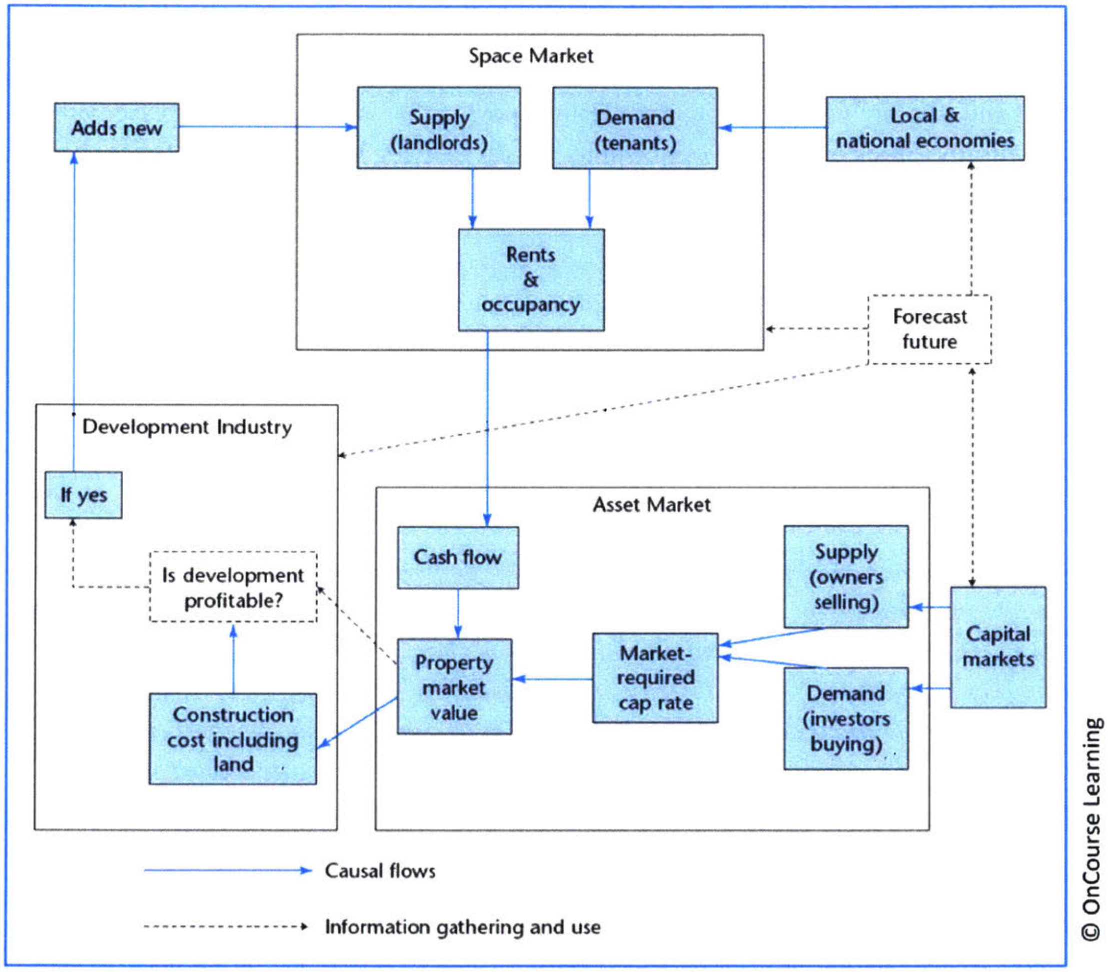
Nowadays, our structures have evolved to fulfill more complex functionalities. Buildings' functionalities have expanded to more than just sheltering. Thanks to the level of comfort and advanced functionalities that we can have in a building, today humans spend nearly 90% of their time living indoors (Klepeis et al., 2001). We can say that "Our Buildings have become a comprehensive life-support mechanism." (E. Allen, 2005)

Furthermore, the complex economic system that exists today has seen in buildings an asset that can be sold, rent and transact for a price. The real estate industry has created a marketplace with a small covariance with the Stock market, an opportunity for diversifying investment portfolios. Buildings have become more than places to live, work and play; they have become assets that can be evaluated and transacted between investors.

Today this interaction between the financial industry, real estate developers, and occupiers has created what is known as the Real Estate System (Geltner, Miller, Clayton, & Eichholtz, 2014). The System has three main components: the space market, the asset market, and the development industry. Figure 1-1 shows these interactions as a "system dynamic model" which illustrates how the components dynamically evolve. A more detailed description of this System can be found in "Commercial Real Estate Analysis and Investments.":

> *"The three large (enveloping) boxes in the exhibit represent the three main elements of the real estate system: the space market, the asset market, and the development industry. Within the space market, we see the interaction of usage demand with the current stock of physical space supply, which determines current rents and occupancy levels in the space market. Underlying the demand side of the space market are the national and* ***local economies****, which determine the need for certain quantities of physical space of various types as a function of the cost (rent) for such space. Governing the amount of physical space on the supply side are the past and current activities of the* ***development industry****.*
>
> *Moving down to the asset market, we see that the space market determines the current operating cash flows produced by the real estate assets that are the fundamental subjects of the asset market. This operating cash flow interacts with the cap rates required by investors to determine current property market values in the asset market. Both the supply and demand sides of the real estate asset market consist of* ***investors****, those currently on the "buy" side and those currently on the "sell" side, either in general or for specific assets. All of these real estate investors are operating within the broader capital markets, which encompass other forms of asset and money markets. Investors' desires and perceptions about the investment risks and returns of real estate assets, as compared to other types of investment opportunities available elsewhere in the capital markets, determine the current market cap rates investors require in real estate deals. A key determinant of cap rates is also investors' forecasts about the future of the relevant space market, on both the demand and supply sides, so as to predict the likely future course of rents…*

Figure 1 - The real estate system: interaction of the space market, asset market, and development industry



Source: Geltner, D., Miller, N. G., Clayton, J., & Eichholtz, P. (2014). Commercial real estate : analysis and investments.

> *…the real estate system… is, in principle, forward-looking to varying degrees in several aspects of the system. Not only must developers be forward-looking to account for construction time, but the space market is also forward-looking in that many users of space require long-term planning for their space needs and much space is rented out under long-term leases lasting typically from two to ten years. But the greatest incentives for peering into the long-run future probably reside in the asset market part of the system.*

Each part of the systems has their unique players that work separately from each other and some of their motivations not necessarily match. Occupiers -understood as companies that rent or build these spaces to use them for their business operations- see more as an operational asset than an investment opportunity, their motivations are aligned with their business goals and not as much to a development profit. Hence corporate users value real estate for the functionality that it gives them.

However, the same property can be seen from a very different perspective by an investor or a developer, who values real estate for the rents and cash flows that it can produce.

Real estate produces value in different ways for the players in the industry, and although not all of the players have the same goals, all of them are linked. The occupier is willing to pay rent for space while it has the amenities, location, and specifications that he is looking to have. Developers have to answer to both occupiers and investors. They can profit from these rents if they can answer to both, by building buildings that respond to the immediate demands of occupiers and, at the same time, are flexible enough to "learn" and adapt to new requirements that made them a feasible long-term asset for investors.

Understanding the actual effect of the office space disruptions is a challenging task. For that, it is essential to understand the motives behind each player, what does technology mean to them, and how a win-win scenario can be accomplished. The next two chapters (3.1 and 3.2) will focus on analyzing what new technologies advances have meant for the workspace from both the occupier and the owners/developers perspective, to try to understand if its possible to create a win-win relationship between this two players.

1.1. A brief story of the space market: economic forces, technology, occupiers and the workspace

Technology in the workplace has played a significant role in how companies occupied and used their spaces. Technology has started an escalating evolution since the 50's hence office buildings have been in a continuous evolution ever since. Back in 1960, Harvard Business Review (Hoos, 1960) pointed out some of the disruptions that computers were making in the office environment. Fears about the office automatization and replacement of workers by computers was a topic that entangled minds of economic researchers and company executives. What would be the work of tomorrow? Are we going to work in the same spaces?

Soon new layouts propositions and architectural trends like the open-floor layout started to appear in the 60's and 70's, and studies about their performance follow them. From Employee Reactions to an Open-Plan Office (Oldham & Brass, 1979) to Speech Privacy evaluations (Moreland, 1989) were made. Some of the studies are still relevant to the challenges faced today by office spaces and layouts.

However, it was until 1975, with the appearance of personal computers, where office buildings started to face significant disruption. New technology discoveries started to catch people's imagination (Poppel, 1982; Stone & Luchetti, 1985), and new companies emerged with business models that were almost impossible to imagine. "A company without offices" (Collins, 1986) could be read in a magazine article, which described how F International, a company with a workforce of more than 1,000, and operations in three countries, could maintain a 30% annual growth rate without offices. This new business model was possible in part thanks to the new technology available that enabled employees to use a new workspace, their home!

Later on, in 1998, companies like Xerox and AT&T started to explore new work schemes like home-office and shared office spaces (Apgar IV, 1998). In an article for Harvard Business Review AT&T publicly showed their shared-offices pilot program achievements which claimed to have reduced their rentable area by 60%, and generated savings of 2 million dollars on a five-year term.

At that moment, Technology appeared to have disrupted the industry in a very critical way. Telecommuting in conjunction with other new trends like shared-offices schemes dawned with ending the office market. "Telecommuting is the office market killer" some people venture to say. Would this suddenly create an overstock of office spaces? It was a question that haunted real estate developers and investments funds since this could have created a reduction in rent prices and therefore the value of this assets. The uncertainty pushed MIT Center for Real Estate researcher (Shiga, 1997) to look into the effect of telecommuting on office demand. Surprisingly, the study did not find any significant reduction of office space consumed, although the author cautiously said that it was too premature to see the impact that telecommuting would have on office demand. However, a far-reaching change was easily appreciated, the growth of the suburban office market at the expense of the CBD.

So what was driving this change? What was the role of technology and telecommuting on all of this? To answer that question, MIT Prof. William Wheaton formulated a study (Torto, Wheaton, & Southard, 1998; Wheaton, 1996) to understand the drivers behind this new developments. The study realizes that at the beginning of the 90's, industries started to rely more on telecommuting than face-to-face communication which gave companies greater location flexibility. At the same time, given that cities tended to develop horizontally rather than vertically, commuting to the CBD became more burdensome, and as this increased potential suburban work sites offered the prospect of far shorter work trips. With this situation and thanks to new technological innovations, companies turned to the suburban advantage:

> *In principle, firms locating at these suburban work sites can attract a labor force at a lower wage. Thus the wage paid comparable workers in the suburbs can be significantly lower than that in the CBD. Because labor represents the primary business cost for office firms, wage differentials can provide a powerful advantage for firms that decentralize (D. P. Timothy, 1995; D. Timothy & Wheaton, 2001)...*
>
> *... With such savings, why don't all firms move to the suburbs, and more specifically, to those suburbs with the most cost-effective commuting and lower wage costs? Several considerations put the brakes on such wholesale decentralization. First, many employers use a diverse labor force, while suburban work sites often are surrounded by communities that offer housing only for the more affluent. Without a broad range of housing nearby, some suburban workers might have to commute almost as far as their CBD counterparts. The transportation systems in metropolitan areas are also a consideration. Not all suburbs*

> *are easy commutes, particularly workers who commute around the metropolitan's rim rather than along the spokes.*

As a result of this, the suburban office's market growth during those years. However, it is essential to emphasize a remark made in that study:

> *"Yet for all of its economic importance, the telecommunication revolution is less cause than the catalyst for suburban office growth. There is a more fundamental suburban advantage. This advantage arises from the operation of urban labor markets."*

Is important to keep in mind this statement, since it was not Telecommuting what was driving the changes; it was a more profound economic force that moved companies to change their real estate location strategy. Technology just opened the possibility to enhance the value of suburban offices by eliminating the barriers of communications.

1.1.1. Technology and its influence on physical location

As mentioned before, the 90's was an important office migration period caused by strong labor economic forces that, with the help of telecommuting (technology), pushed corporate users to the suburbs. Studying this migration is interesting because it is one of the most recent changes in the office market where technology played a catalyst role and helped to magnify its effects. This study could help us understand better the role of technology in the workspace and their relation to the real estate market.

To begin with, one crucial factor that technology enabled in the 90's was the capacity of corporate users to be more flexible with their physical location. Technology pushed the boundaries of communication and opened new channels that people could use to work remotely with their peers and clients; people did not have to be in the same place as other people anymore, it was as easy as picking up the phone to contact someone that was not physically there.

Telecommuting has advanced during this last 20 years, pushing communication barriers even further. Laptops and cell phones appeared, and in 2007 the first iPhone was launched. Since then, telecommuting has become ubiquitous and part of everybody's life. People no longer rely on the phone to work, Skype, Facetime, and more recently VR and Holographic lenses have made telecommunications more interactive and natural. Technology has reached a new height that was unreal for people's imagination back in the 90's. Now, it is also possible to find intelligent personal assistants like Alexa, Google Home, and even the spin-off from the MIT Media Lab, Jibo. Even further, people do not need to own a computer to store their information they can now have access to all their files from almost any network in the world, thanks to cloud storage an computing services.

Since 1989, people have been tracking these technologies and their possible application to the work environment. One of the most known matrices, the CSCW matrix, considered the work context according to two dimensions. First, the physical location of the work collaborators. Second, the time dimension: whether is at the same time when work takes place or not.

Table 1 - Basic Business Team Needs and Groupware Solutions

	Same Time	**Different Time**
Same Location	Need: Face-to-face meeting e.g., Conference Rooms, Decision rooms, Single Display Groupware, Shared Table, Wall Displays, Interactive whiteboard, Room ware.	Need: Administrative, Filing, and Filtering e.g., Cloud Storage, Public Display, Shift Work groupware, Team Rooms, Project Management.
Different Location	Need: Cross-Distance Meetings e.g., Conference Calls, Screen Sharing, Video Teleconferencing, Instant messaging, chats/MUDs, Virtual Worlds, multiuser editors.	Need: Ongoing Coordination e.g., Email, Bulletin Boards, Group Calendar, Blogs, Asynchronous conferencing, Workflow, Version controls, Wikis.

Source: The Computer-supported cooperative work (CSCW) Matrix categorize the context of social computing according to time and location. (Image adapted from (Johansen, 1989))

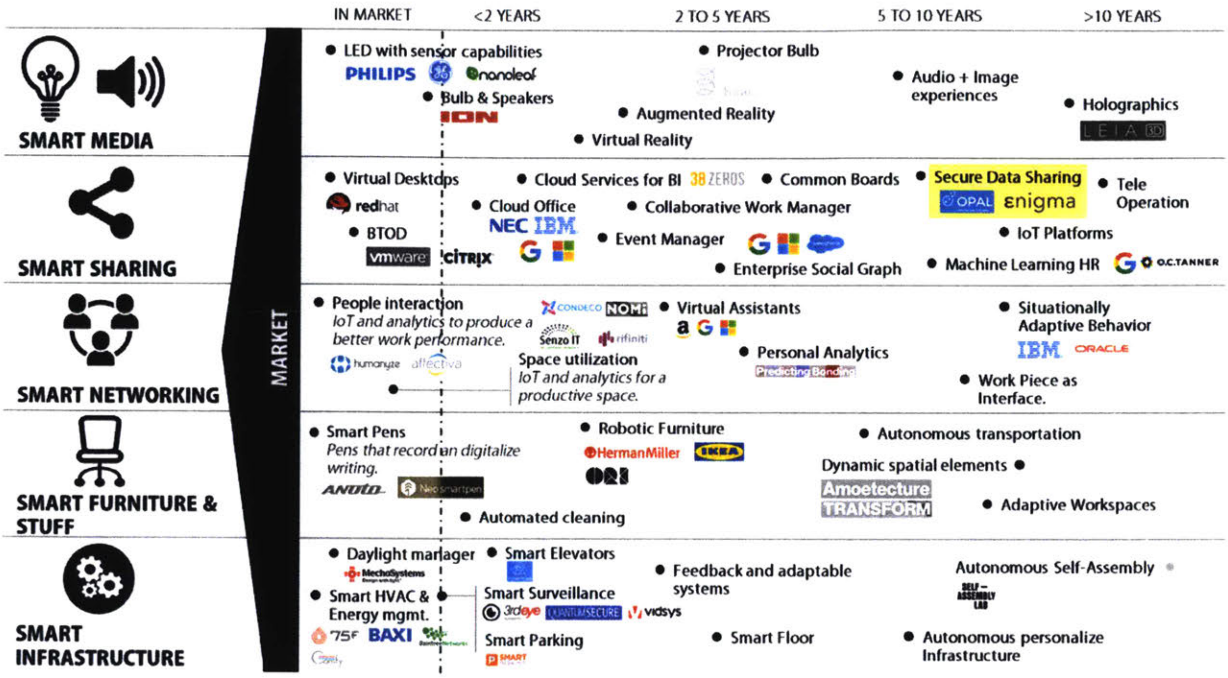
It was these new capabilities brought by technology, that moved people to think that office spaces were no longer needed. This belief has not disappeared ever since furthermore has been magnified with the appearance of new gadgets and technology over time.

Nowadays, telecommunication is something that is taken for granted, and a whole array of new technologies are coming to the market (**Figure 2**), some of them are already changing the way people are starting to use their spaces.

Moreover, like retail, which transformation is more visible, change in other real estate products will start to appear. In the next couple of years, technology will push the rise of new real estate products and processes, leaving us with one question: as a developer, how can we face a challenge that does not come from within but from the market itself?

To answer this question and now that we have explored what role did technology play in the transformation of real estate in the 90's, we will focus on understanding what changes are happening nowadays, and what building blocks do developers can use to face these new challenges and create new opportunities.

Figure 2 - Innovation in the Workspace



1.1.2. A new economic force: The Millennial Generation and their effect on the office's location

Similar to the migration that we study in the previous chapter, in the last five years, cities have faced a similar migration but in the opposite direction: the renaissance of the CBDs. Some industry experts say that the mix of Millenials' preferences to live in urban core areas above the suburbs and the companies' struggles to attract new talent had pushed these last ones to move their headquarters and offices in or near the CBD. For example, as JLL's report shows (JLL, 2016), Chicago downtown area has continued to show strong rental growth, thanks in part from the significant migration seen from companies that moved from the suburbs to the CBD in recent years.

The millennial behavior has created a fascinating discussion between economist. Some researchers, like USC Urban Planner Professor Dowell Myers and University of Toronto Professor Richard Florida, claimed that with the aging of the population (Myers, 2016) we are about to reach the "Millenial Peak." In the coming years, they expect to see a decrease in millennials preference for urban areas hence a reduction in the urban core growth, driven by people looking for more affordable houses with ample spaces. Since last year, some news already claimed that numbers are starting to show this new trend (Bahrampour, 2017) where the suburbs surpassed the growth of cities for the first time in six years.

Others, like Joe Cortright, President and Principal economist of Impresa, claimed that this trend is going to continue and that millennials' migration to urban core areas will do nothing but increase (Cortright, 2017), maintaining the urban revival trend.

Despite the differences in arguments, it is clear that economic forces of the labor market are creating changes in the office market again, and corporate users are aware of the uncertain future that this creates.

Reading through Amazon's 2017 2HQ RFP it is possible to find some hints on how some corporate users are trying to face this new changes from a real estate perspective. As mentioned in their document, Amazon is looking for a location:

- Nearby a dense metropolitan area.
- That provides easy access to a skilled workforce.
- Excellent transportation infrastructure.
- Sustainability.
- Network connectivity.

Like Amazon, many other companies have a similar strategy, pushing and accelerating the rebirth of the Central Business Districts (CBDs) since they provide the "live, work and play" environment that attracts millennials.

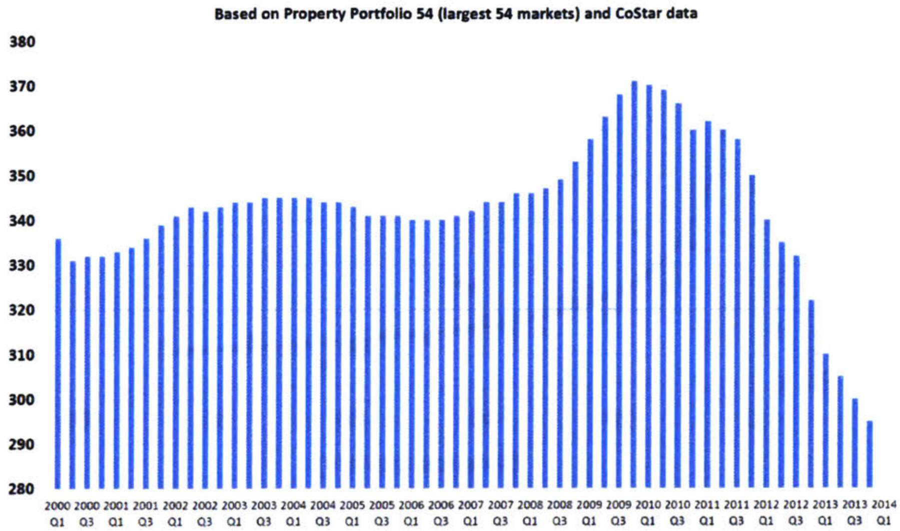
CBRE 2017 Global Occupier Survey Report (CBRE Research, 2017) gives us another interesting point of view of view on how occupiers are assessing their office locations. Most of them are worried about an approach that incorporates both Space Efficiencies to reduce costs, and Flexibility as a de-risking workplace strategy, which will let them prepare their real estate portfolio for the growing uncertain economic future.

> *"Sophisticated occupiers are seeking ways to create flexibility with the goal of 'de-risking' their portfolios because the future is hard to predict."*
>
> *– Brandon Forde, Executive Managing Director of CBRE Advisory & Transaction Services*

Given the labor and economic forces acting over occupiers, new physical space configurations mixed with technology had been presented as possible solutions to improve flexibility and business agility, which already started to show some effects in space demand. A recent study (G. Miller, 2014) by Norman G. Miller, Professor in Burnham-Moores Center for Real Estate at the University of San

Diego, found that U.S. Companies have started reducing and optimizing their real estate footprint and their effects are beginning to be visible (Figure 3[1]).

Figure 3 - US space per worker trends in square feet



Source: G. Miller, N. (2014). Workplace trends in office space: implications for future office demand. Journal of Corporate Real Estate

However, in search of flexibility and agility, companies have to achieve this without losing their workforce productivity. This has pushed changes in architectural and interior design that are looking to enhance air quality, thermal comfort, daylight exposure and interior lighting, and use Biophilic Design Principles (Terrapin, 2014). Given that all of these claimed to be related to employee satisfaction, health, and engagement, hence better productivity.

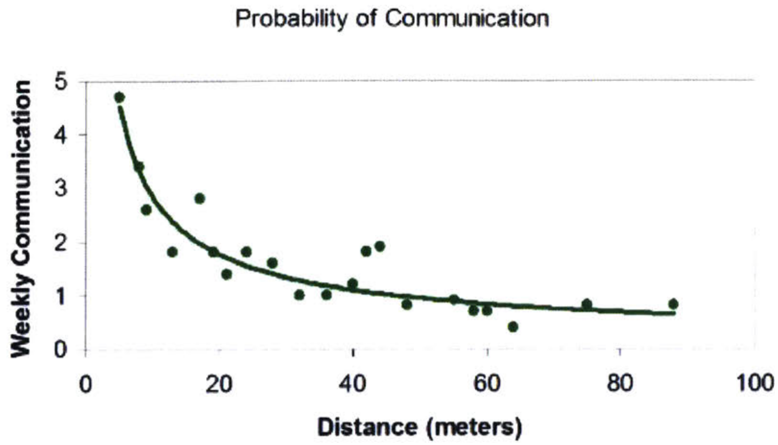
1.1.3. The coming back of the office space and the birth of smart buildings

With more powerful technologies in the market, why have not we seen a more aggressive transformation on the way corporate user work? Why if we have almost ubiquitous communication do we still need office spaces? Why have office spaces not disappeared? To answer this question, we turn to see the research done by Thomas J. Allen a Professor at MIT Sloan School of Management and MIT's Systems Engineering Division, whose life has been devoted to studying technology and innovation management. Allen had explored the relationship between organizational structure and behavior, and a significant part of his studies has been focused on quantifying how a building's

1 Figure 2 is based on Rentable Building Area (RBA) that differs from what the International Facility Management Association knowns as usable area. Usable area is 84% of the rentable building area. Thus, what a developer may call 200 square feet per worker using RBA is only 168 square feet per worker to a facility manager.

layout influence communication. These studies created what people now know as "The Allen Curve" (T. J. Allen, 1984; T. J. Allen & Henn, 2007).

Figure 4 - Allen Curve: The probability of a pair of people in an organization communicating with each other declines rapidly as the distance between them



Source: (T. J. Allen, 1984; T. J. Allen & Henn, 2007)

Allen's study demonstrated that the probability of a pair of people in an organization communicating with each other declines rapidly as the distance between them.

> *By measuring the walking distances between every pair of engineers or scientist in the organization and relating the distances to communication frequency. A curve can then be plotted that shows the probability of communication declining with distance. As it turns out, the probability that people in a given organization will communicate with each other declines precipitously the farther away from each other they are situated and reaches an asymptotic level at about 50 meters.*

What is essential about the Allen Curve is that it demonstrated something that nobody was taking into account about technology: human nature and the way we communicate with each other. Although technology created more channels that people could use to interact with each other, people minds, and human nature still relies on face-to-face contact to transfer high-complexity information.

> *Readers may legitimately wonder whether this analysis of the effects of distance on face-to-face communication also applies to other communication media. After all, wasn't the telephone invented in part to resolve the problem of distance? And, therefore, shouldn't the probability of telephone communication increase as distance increases? It sounds reasonable to presume that the telephone substitutes for face-to-face communication. What about electronic mail? Will it also function this way?*

> *We expected affirmative answers to these questions, but what we found is a bit different. For example, rather than finding that the probability of telephone communication increases with distance as face-to-face*

probability decays, our data shows a decay in the use of all communication media with distance (following a "near-field" rise)...

Even now, technology as a communication system still has a very profound limitation, they are "bandwidth limited," at least in its present form.

We mean this in more than just the physical sense. Discussing anything that is complex or abstract by telephone or electronic email is very difficult. We need to meet directly with the person. We may phone or send an e-mail, but that is usually to arrange the meeting at which the real communication takes place...

The reasons for this are manifold. First, many things, particularly technical ideas and problems, are difficult to communicate with words alone. We need assistance of diagrams or sketches. In addition, we often need the feedback that comes from looking into the other person's eyes, which communicate understanding. Anyone who has ever taught a class will testify to this. When that glazed appearance comes over the students' eyes, you know you've lost them.

Similarly, in describing an idea or technical problem to people, you can tell whether they are following you. Body language, particularly from eyes, provides unspoken feedback that is very powerful. If the indication is negative, you are prompted to restate the information in a different way. This feedback system is invaluable in guiding communication. Telephone communication does not typically allow this feedback. Videoconferencing and some new forms of e-mail allow people to see one another, an this can be a very great help, but none of these forms yet provide the same broadband communication available in a direct encounter. Consequently, videoconferencing, at least thus far, provides insufficient resolution to afford the same precision in eye contact and the accompanying feedback available in face-to-face encounters. Written communication and the most prevalent forms of electronic mail suffer the additional difficulty that the are asynchronous. Any feedback at all on understanding is delayed in time. Most videoconferencing suffers the additional drawback of being restricted to formally scheduled meetings. This is a help mainly for communication for coordination, the first of the three types of communication discussed earlier. The second and third types-communication for information and inspiration-are seldom conveyed through formal meetings.

A more recent study (Claudel, Massaro, Santi, Murray, & Ratti, 2017) examine the faculty collaboration patterns at the Massachusetts Insititute of Technology, through academic outputs, and their organizational structures over a 10-year time span (2004 – 2014). With all the technology available and even that MIT Campus Architectural Structure promotes collaborations, their results match Allen's findings in the 90's.

..we find that the probability of a collaboration between two agents decays exponentially with their spatial proximity, as previously observed in research that addresses a larger spatial scale. Probability adheres to a negative exponential function with a remarkable degree of consistency–not unlike, for example, the dissemination of dandelion seeds. One is more likely to find a seed close to the dandelion flower, and the likelihood of finding a seed decays exponentially as the distance increases. In the case of MIT faculty, one is more likely to find a collaborator close by. Co-authors have a higher tendency to collaborate at a

distance 0, suggesting co-authorship within a laboratory or department, while co-invention is more regularly spaced along the exponential curve.

These studies help us prove that face-to-face interactions and proximity play an essential role in innovation and work productivity. Even with the technology available nowadays, people need to be in the same place to interact and collaborate with each other, technology has not managed to replace face-to-face interactions. This fact has made us understand that office spaces are still essential for today's economy since they create merely the synergy that humans need to work correctly.

In this context, technology has given occupiers the possibility to measure a whole new dimension of variables. Sensors have merged with network communications protocols creating what we now call as the Internet of Things (IoT). These devices like occupancy, temperature, and humidity sensors, cameras with emotion recognition algorithms, sociometric badges, and air quality monitors help us measure variables that were previously impossible or very complicated to get. From peoples physical location to room temperature and air quality, we are now able to measure a whole new dimension of the environment and how people behave in it.

An exciting application of this technology, which looks to improve work performance, was proposed by Benjamin Waber CEO of Humanyze and former MIT Media Lab Researcher. During his studies at MIT he used sociometric badges to study human behavior in the workspace. Their discoveries have been stunning and have helped occupiers to understand how to create a more productive workforce. In his research, he found that Allen's curve holds even with the advance of technology (Waber, 2011), but also other variables affects the productivity of the workforce. More relevant to our topic, Waber found that workspace productivity is not only influenced by physical proximity but by other factors, that we are now able to measure and react.

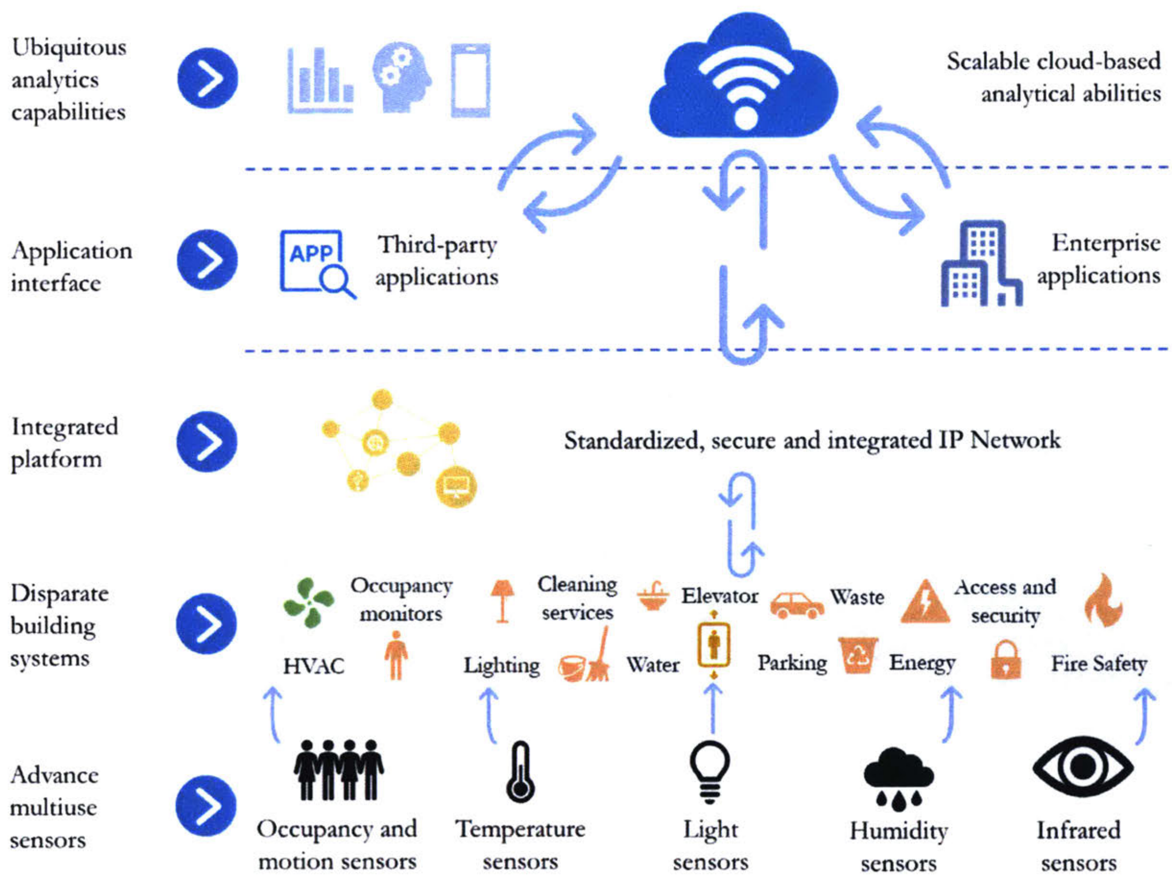
The manipulation of existing spaces within an organization is particularly appealing to those not able to construct a new space that incorporates the optimal set of workplace design elements. Consider the open office floor plan, a solution that organizations continue to utilize with the intent of bolstering F2F communication in spite of a growing body of research demonstrating its negative effects on stress, job performance, and coworker relations (Brennan, Chugh, & Kline, 2002). The continued implementation of this layout demonstrates that there are cases in which, despite negative effects on employee well-being, its potentially positive effects on F2F communication render it a desirable option. However, despite widespread use, it remains difficult for such organizations to gauge precisely how spatial manipulation affects communication (Sailer, 2007). This difficulty has been partly attributed to a lack of consideration for experimental design to measure the effects of changes in workplace layouts (Davenport, Thomas, & Cantrell, 2002).

These new capabilities leave us thinking, what if buildings can give us this information? What if buildings can measure and adapt to the specific need of every occupier? Even further, adjust to the particular needs of every person in the building. Questions like these have pushed the occupiers to think a step ahead of not only green buildings but to buildings that go beyond that, buildings that are smart.

Most of the companies lease their spaces from landlords, and not all of them can build their offices and facilities. If occupiers' IoT devices could talk with the landlord's systems, each occupier would be able to take full advantage of their real estate; they could use the data generated for multiple things, from operational efficiencies to workplace productivity.

As seen in the figure below (**Figure 5**) Smart Building will be not only a physical structure but a digital platform that would work enhance the occupier experience, and this platform involves both the occupiers and the developers/landlords.

Figure 5 - IoT information value stack for CRE buildings



Source: Jim Young, "BioT – Building Internet of Things™," Realcomm, January 23, 2014; Deloitte Center for Financial Services Analysis.

Now occupiers can measure a new dimension, productivity, and this has profound changes on how they approach spaces. Companies are not focused only on location, now they look for more productive and efficient areas, and Smart buildings rise as a possible answer to this new requirement. The only question that remains is, does occupiers will be willing to pay premium rent to have a space in these buildings?

1.2. The effects of technology on the asset market

Technology not only has an impact on how occupiers use buildings but also in the financial performance of these. Green and Fiber Lit Buildings have been the latest innovations introduced in this type of assets. Benefits go from operational expenses (OpEx) reductions to premium rents what makes innovation investment interesting for some developers. The first claim is still challenged since some researchers have found that OpEx are the same between Green and non-Green buildings given the more advanced systems that require more costly specialized technicians.

Nevertheless, with the rise of Smart Buildings that go beyond Green and Fiber Lit Buildings the search for financial benefits that help developers understand the premium on investing in these innovations have become a crucial topic in the industry.

In the next chapter, we will analyze how technology has managed to create financial gains, and we will explore what new benefits can Smart Buildings bring to the market.

1.2.1. Drivers of Innovation

Nowadays, sustainability is the lead driver of innovation in the sector and although at the beginning returns on green innovation where not immediately evident, today, thanks to the rich and extensive literature we now know that investing in green buildings can improve the financial performance of a building or a real estate portfolio.

Morgan Stanley estimates than landlords in the top 10 office markets in the U.S. spend nearly $7.4 billion on utilities each year, which at prevailing capitalization rates landlords have liabilities of more than $128.4 billion embedded in their property operations. The research continues by mentioning that technology can help reduce this costs by around 3 to 30 percent, that would translate in the potential to create between $3.5 and $34.9 billions of asset value in the office market.

These gains are also visible in large-scale portfolios, as one recent study (Fuerst, 2015) found that 1 percent improvement in a Real Estate Investment Trust's (REIT) Global Real Estate Sustainability Benchmark (GRESB) score was correlated with a 3.4 percent increase in return on equity. Another study (Eichholtz, Kok, & Yonder, 2012) found that as the amount of LEED projects in a portfolio increases by 1 percent, the market beta of REIT's decreases by 0.14 percent. These two studies help us see that value is created in multiple ways and a thorough evaluation to discover the potential benefits of innovation is worthwhile since the gains can be substantial.

However, what is driving innovation in the industry?. Morgan Stanley (Morgan Stanley Insititute for Sustainable Investing, 2016) found three emerging drivers that have been pushing change in the sector, which are:

- ***New standards and policy**, which are encouraging or requiring buildings to improve resource efficiency.*
- *Innovation in building technology, which is increasing the **sustainability performance gap** between buildings.*
- *Shifts in **stakeholders expectations**, which are prompting buildings to provide new sustainability capabilities to attract and retain tenants.*

These drivers created by internal and external factors of the built environment will continue to evolve, affecting different areas and creating opportunities for the ones that know how to take advantage of them now.

1.2.2. Evidence of value creation through innovation in real estate

During the last decade, mainly thanks to a rising flow of data that has started to be common in the industry, studies and researchers were able to measure innovation in real estate in a more profound way (See **Table 2**).

Studies like this have been beneficial to understand the effect of innovation in the industry and have presented a more clear panorama of what innovation means to developers and occupiers.

Value Creation through sustainability

Statistical studies conducted by academic and researchers apply modeling techniques to large databases of properties, their research has given us enough evidence that green innovation creates value for real estate projects. Evidence has also pointed that gains are not produced only by reducing the operational expenses of a project but in many other ways like rent and occupancy premiums, more attractive debt terms, higher occupancy rates, reduction in insurance costs, among others.

Three studies focused on the U.S. found evidence of different ways green innovation creates value. The first research (Eichholtz et al., 2010) found that the same commercial buildings with an Energy Star certification will rent for 3 percent more per square foot; the difference in effective rent was estimated to be 7 percent. The same study establishes that the increment in the selling price could be as high as 16 percent.

The second study (Wiley, Benefield, & Johnson, 2010) also found evidence of rent premiums by roughly 7 to 17 percent for Energy Star and LEED certifications respectively. They also found that energy efficient buildings have better occupancy up to 10 to 18 percent more than similar properties in the market.

The third study (Fuerst & McAllister, 2011), also found evidence of 4 percent rent premiums and 26 percent in price premia for Energy Star buildings and 5 percent rent premium and 25 percent in price premia for LEED buildings.

There have also been studies focused on other countries, Andrea Chegut, MIT Real Estate Innovation Lab Director, found evidence (Chegut, Eichholtz, & Kok, 2014) of 19.7 percent rent premium and 14.7 percent price premia for BREEAM certified buildings in London. In Australia (Newell, McFarlane, & Kok, 2011) another research found a 5 percent rent premium and 12 percent in price premia for Green Star certified buildings, it also found 9 percent price premia in 5 stars NABERS accredited buildings.

However, while all of this studies provide a positive relationship between sustainability innovation and price premiums, it is clear that the value of sustainability in particular projects depend on variables as building location, characteristics, resource availability, costs, lease terms and many others. Not all the projects will immediately obtain these premiums just by embracing a green strategy. Nevertheless, it is worth to emphasize that value created by green buildings can be very diverse and not restricted to the more obvious ones (i.e., reduce operational expenses).

Finally, a more recent MIT study (Geltner, Moser, & Minne, 2017) focused explicitly on green retrofitting of existing office buildings. The study found substantial value enhancement in green retrofit projects in the range of 10 to 20 percent and also evidence that retrofitted green buildings provide investors with lower asset price volatility.

The study also found that the demand for green is income-elastic and premiums disappear during a financial crisis or market recession. This new insight provides us with an interesting perspective on one possible motive on why real estate innovation has not flourished as expected in the last couple of years because under global economic uncertainty innovation has the risk to lose its premium.

Value creation through flexibility

Until now, technology and real estate innovation primary focus has been in sustainability. Green buildings common objective has been to reduce the overall impact of the built environment on human health and the natural environment by efficiently using energy, water, and natural resources while reducing waste, pollution, and environmental degradation. However, recent technology innovations have not only improved the energy efficient systems but have also added new functionalities and dimensions to the scope of our building expectations.

It is true that sustainability started a new trend in well-being and productivity. Researchers have found (J. G. Allen et al., 2016; Kang, Ou, & Mak, 2017) that some work environment factors like the physical layout, air quality, thermal, acoustic and lighting environment correlates with team productivity. However, new technology that goes beyond green let us create more flexible spaces that can produce offices that boost productivity and collaboration.

The possibility to create adaptable offices brings a much more exciting factor for the occupier since a simple small improvement in productivity can mean even higher gains for the company. A smart building is not only selling space and sustainability but flexibility and productivity.

However, flexibility has not only been offered by building technology. In a time when a company's lifespan has decreased, and economic uncertainty has increased considerably, a flexible lease term that let companies move through different locations in spaces prepared to enhance collaboration is an interesting proposition for corporate users. This opportunity has created an explosive number of startups that with innovative business plans offer the so desire flexibility with a "cool" factor. One of these companies is WeWork. Based in New York, they proposed a new business model, Space as a Service, were without owning any real estate assets they can provide offices services for startups and companies looking for short-term leases. The company currently operates more than 156 offices around the world and serves more than 120,000 members. For this achievements, WeWork has achieved a $20 billion valuation: topping the market caps of office REIT's like Boston Properties ($18.25 billion) and Vornado Realty ($17.7 billion).

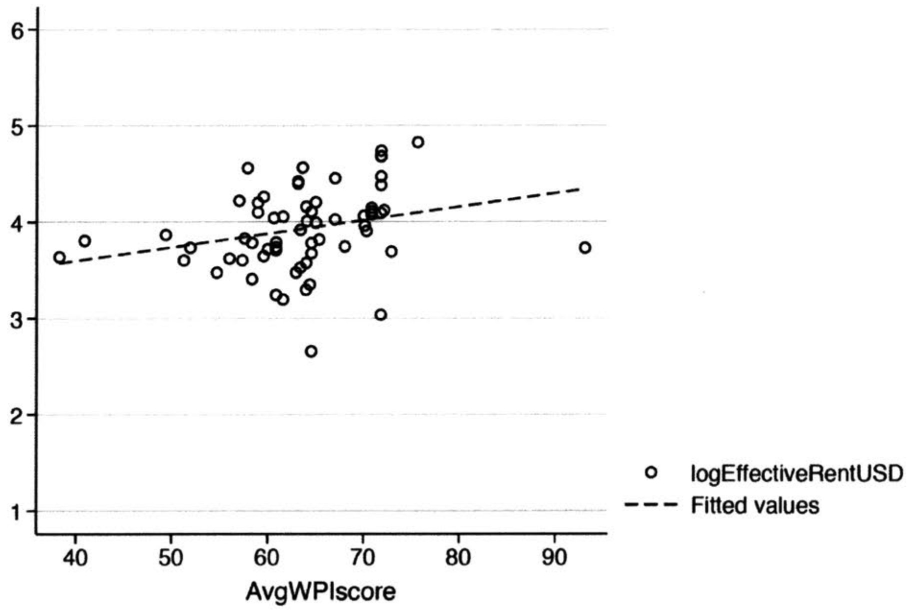
Value creation through good design

Thanks to studies like the one done by Allen in the 80's and more recently to the ones done with sociometric badges by the MediaLab, we know that space plays a more important role than just a physical location. Good spaces can become a competitive advantage for companies; they can become an asset that improves the productivity of their workforce, help them attract and retain the best-talented people, provide a flexible structure and reduce risks and costs.

In a recent master thesis (John & Puri, 2017) explored the relationship between rent premium and Workplace Performance based on Gensler WPI℠ scores that relate performance with physical design. They found that indeed good designs reflected on higher WPI℠ scores produce higher premium rents than lower scored WPI℠ spaces.

> *The premium effect of WPI-scored leases is best observed when analyzed with respect to location characteristics (neighborhoods) and time-fixed effect (lease commencement date) reflecting a premium of 12.7% over non-scored leases… It is also important to note that Below Average Performing Workplaces achieve 10% to 15% lower effective rents than non-treated leases, thus strengthening the case for considering workplace performance as a factor that drives financial value of leases.*

Figure 6 - Effective Rent vs. Average WPI Score



Note: Figure 6 illustrates the best-fit line for the logarithmic of effective rent per net square foot of commercial office space to the Average WPI score.
Source: (John & Puri, 2017)

This discovery is particularly exciting since it found that tenants are willing to pay a premium rent of 12.7% for good office designs that make them more productive.

Table 2 - Studies on Real Estate Innovation

Report	Geography	Certification Involved	Price Premia	Rent Premium	Occupancy Rate Premium	Lease Renewal	Cost Premium	Reduced Energy Use	Operational Expenses**
(Kats, 2003)	US	LEED Certified					0.66%	28.00%	
		LEED Silver					2.11%	30.00%	
		LEED Gold					1.82%	48.00%	
		LEED Platinum					0.065		
(Norm Miller, Spivey, & Florance, 2008)	US	Energy Star	5.3%		2 – 3%-				
		LEED	9.9%		2 – 4%				
(Wiley et al., 2010)	US	Energy Star		7.3 – 8.6%	10 – 11%				
		LEED		15.2 – 17.3%	16 – 18%				
(Eichholtz et al., 2010)	US	Green Rated (LEED or Energy Star)	15.8%	9.7%	11%				
(N. Miller, Pogue, Saville, & Tu, 2010)	US	Energy Star						-15.0%	3.7% more OpEx than non-Green
(Fuerst & McAllister, 2011)	US	Energy Star	26%	4%					
		LEED	25%	5%					
(Newell et al., 2011)	Australia	Green Star	12%	5%					
		NABERS	2 – 9%	No Premium					
(Kok & Jennen, 2012)	Netherlands	EU Energy Performance Certificate		- 6.5% rent for non-certified buildings					
(Chegut et al., 2014)	London	BREEAM (London)	14.7%	19.7%					
(Devine & Kok, 2015)	Canada	LEED			8.50%	0%			
		LEED & BOMA BESt			18.70%				
		BOMA BESt				2.1% - 5.6%			
	US	LEED			4%				
		Energy Star			9.50%				
(Geltner et al., 2017)	US	LEED (Retrofitted)	10% – 20%, lower volatility	N/A	N/A				
(John & Puri, 2017)	US, NY	Gensler WPI Index	N/A	12.70%	N/A				
(Devine, Steiner, & YYnder, 2017)	US, UK	REITS							+0.2% OpEx on REIT's with Green Buildings

2. Building level disruptions

As shown in the previous chapter, real estate and how buildings evolve depends on many factors that vary from economic to human behavioral characteristics, it is easy to get lost and hard to understand how all of this comes together.

Given this and to better analyze the disruptive force that IoT and Smart Buildings are bringing to the market we will start by examining this from a functional analysis perspective. The purpose is to understand the more visible changes that technology is introducing to see later how this translates into benefits for the different players in the industry.

2.1. Functional analysis of an office building

As mentioned before, buildings have evolved from primitive structures that provided basic life-support functionalities to a comprehensive life-support mechanism than have become the physical support of our cities and societies. Now, we do not only expect to get refuge from the outside elements, but we are demanding more functions from our structures like thermal comfort, visual privacy, and optimal lighting.

In his book "How Buildings work" (E. Allen, 2005) a former MIT Professor, architect, and structural designer provides an in-depth analysis on how all the different components of buildings come together to create the various functions that we see nowadays.

In the quoted book, Allen mentions that the general functions expected to be performed by buildings can be divided in two: those who arise from human needs and those caused by the needs of the building itself. In this way, it is possible to summarize the building functionalities in fourteen core functions.

Table 3 - Building functionalities

PRIMARY HUMAN NEEDS **Functions arise from human needs**	**SECONDARY HUMAN NEEDS** **Functions that arise from the needs created by the building itself**
1. Provide most of the immediate necessities for **human metabolism**. a. Clean air for breathing. b. Clean water for drinking, food preparation, cleaning, and flushing of wastes. c. Clean spaces for the preparing and consuming food (in many types of buildings). 2. Create the necessary conditions for **human thermal comfort**. a. Control of the mean radiant temperature. b. Control of the air temperature. c. Control of the thermal characteristics of surfaces contacted directly with the human body. d. Control of humidity and flow of water vapor. e. Control of air circulation. 3. Create the necessary conditions for **non-thermal sensory comfort, efficiency, and privacy**. a. Optimal seeing conditions. b. Visual privacy. c. Optimal hearing conditions. d. Acoustical privacy. 4. Control **the entry and exit of living creatures** and human beings. 5. **Distribute concentrated energy** to convenient points for use in powering appliances. 6. **Provide up-to-date channels of connection and communication** with the world outside (e.g., cellphone signal, telephones, computer and video networks). 7. Facilitate bodily comfort, safety, and productive activity by providing **useful surfaces** (eg., floors, walls, stairs, shelves, countertops, and benches). 8. Provide **easy transportation access** to the location area (e.g., parking, shuttle bus, nearby subway station, heliport and taxi hubs).	9. Provide **stable support for the weigh**t of all the people, belongings, and architectural devices in the building and to provide sufficient structural resistance to the physical forces of snow, wind, and earthquakes. 10. **Protect its structure**, surfaces, internal mechanical and electrical systems, and other architectural devices from wetting from precipitation or other water. 11. **Adjust to its normal movements** (e.g., foundations settlement, thermal expansion and contraction, and movement induced by changes in moisture content of building materials, without damage to itself or its content. 12. Furnish reasonable **protection to its occupants**, its content, and itself against damage by fire. 13. **Build it without excessive expense** or difficulty. 14. Capable of being operated, **maintained**, and change in a useful, **economical manner**.

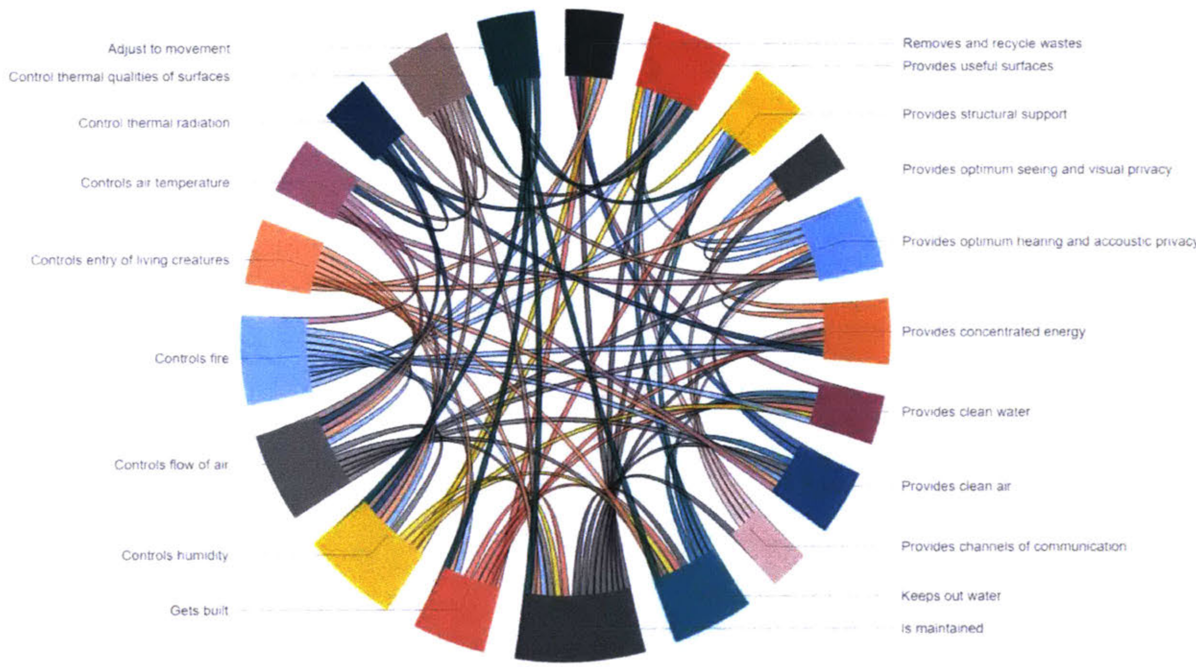
Source: "How Buildings work" (E. Allen, 2005)

This function categorization can be very simplistic and risks to overlook some of the components of the complicated system that a building is. Nonetheless, it is helpful since it provides us with a clearer understanding of what a building is and what people expect from them.

Understanding the basic functions of a building will lead us to understand how these functions generate value for the different players in the industry, because as we mentioned earlier, all of them rely on the building to provide value, but the value obtained and what is the cause that produces it can be quite different from each different player.

It is also crucial to see that all of these functions rely on multiple buildings components and the technology that buildings have install on. Obviously, building components serve more than one function simultaneously, and building functions are heavenly interdependent between each other, which creates a building "ecology," based on a delicate internal balance of a connecting mechanism that works as a richly interconnected system (**Figure 7**).

Figure 7 - Correlation between building functions



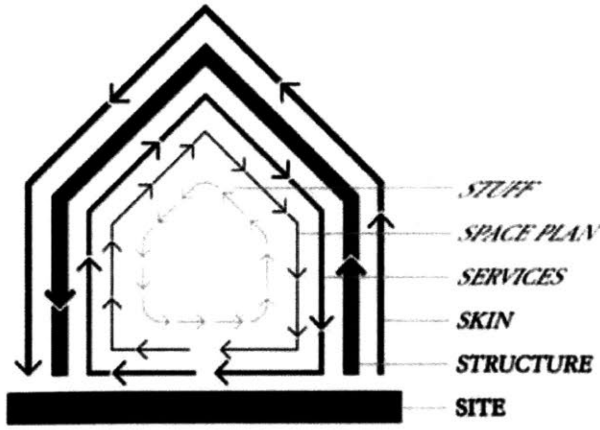
Source: Adapted from "How Buildings work" (E. Allen, 2005)

A developer must realize that a change in one function can affect others and move the internal balance, which can be easily broken. This concerns the developer/owner since this balance is responsible for the future performance of the building, hence the return of the investment. For example, if occupiers decide to build steel studs partitions in their leased space, this will affect the thermal properties of the building, its acoustical and lighting qualities, the air flow and thermal comfort, the usefulness of the walls, the deadweight that the structure will need to support, the fire resistance of the building, and the way is built and maintained. Some of the office functions will be improved, and some will be hindered, which will affect the performance by increasing or reducing the operational and capital expenses since these depend on the harmonious coexistence of all the building's components.

2.1.1. Functionalities and their relationship with Building Components

So what are the components that enable buildings to provide such a variety of complex functions? In his book "How Buildings Learn: what happens after they are built" (Brand, 1994) makes a simple classification of these components, dividing buildings into six parts: Site, Structure, Skin, Services, Space Plan and Stuff. This classification can be complemented with Allen's classification of buildings components which help us create a more detailed panorama of all the components that form the built environment.

Figure 8 - Shearing Layers of Change



Source: "How Buildings Learn," (Brand, 1994)

Table 4 - Shearing Layers and Building Components

Shearing Layers of Change	Building Components
Site Site is eternal	Site
Structure The foundation and load-bearing elements are perilous and expensive to change. Structural life average **100 years.**	Foundation Structure Walls
Skin Exterior surfaces change every **20 years.**	Roofs Windows
Services The working guts of a building. Must of this components wear out or become obsolete every **7 to 15 years.**	Heat/Vent/AC Plumbing Electrical Fireplaces
Space Plan The interior layout can change every **three years to 30 years.**	Ceilings Doors Floor Partitions Finishes
Stuff Furniture can change **daily or monthly.**	Furnishing

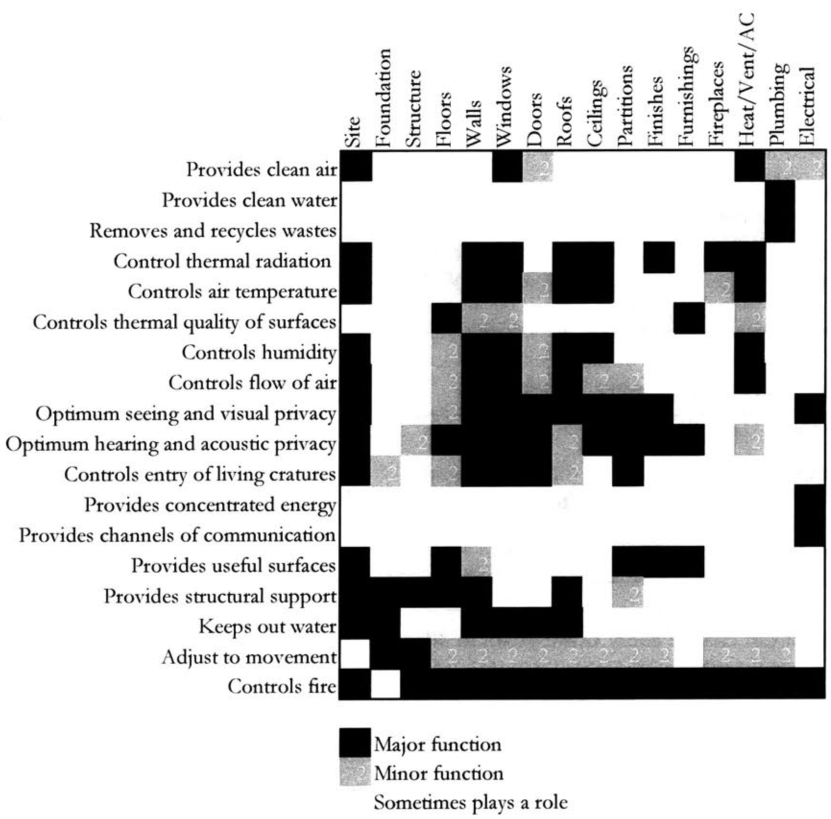
Source: "How Buildings Learn" and "How Buildings work" (E. Allen, 2005; Brand, 1994)

All of the building's functionalities are achieved thanks to these components that live inside or interact in some manner with the structure. The following **Table 5** shows the major functions performed by building's components which are made of a combination of materials with complementary characteristics that serve a multiplicity of functions.

Components are the buildings blocks that architecture can use to create places that provide experiences and useful surfaces that we later can use for the different human activities. The basis for architectural creativity relies on understanding how the order of building blocks work together.

In previous chapters, we also have mentioned two other functions that affect the way we build buildings, the economic and the symbolic functions. Each building must justify each economic existence in dollars terms, and they must be suitable for the activities that they will be hosting inside. These two functions can change depending on the project, but the scientific fundamentals of buildings are always the same. Understanding the first principles on how to moderate the forces of Nature for human occupancy, help us prepare to build well under any circumstances and strategically use technology to improve the benefits that a building brings to both occupiers and developers/investors.

Table 5 - Relationship between Building Components and Building Functions



Source: Adapted from "How Buildings work" (E. Allen, 2005)

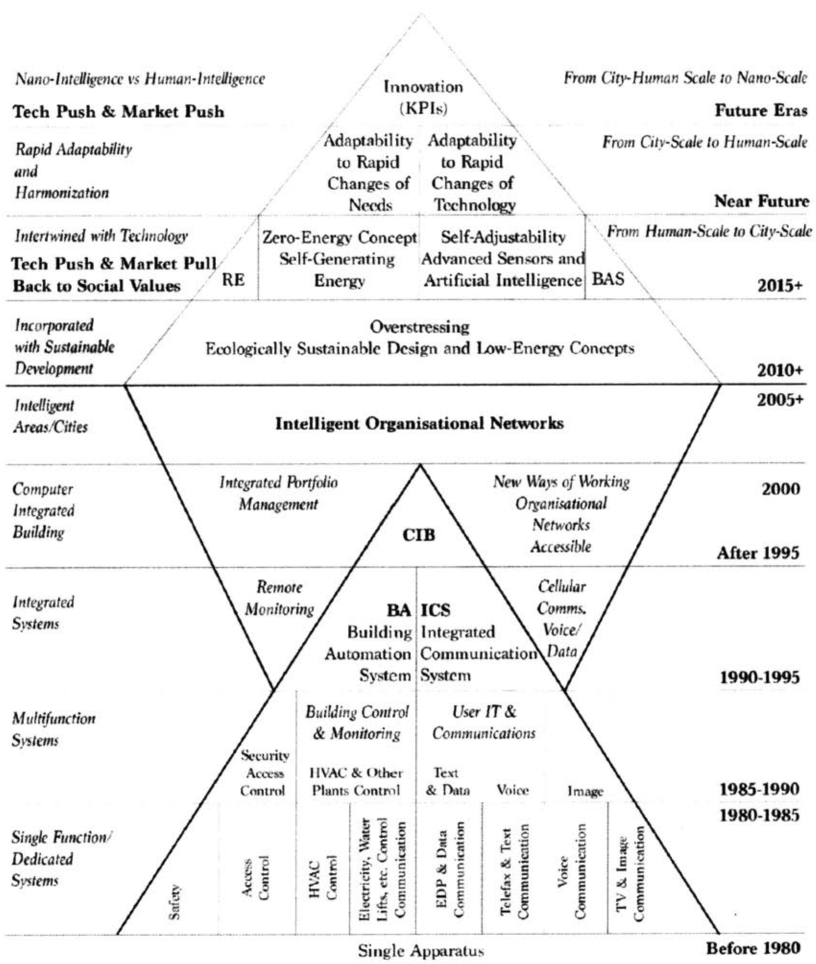
2.2. A definition of a Smart Building

Intelligent Cities, Smart Buildings, High-performance building, and related concepts are not a new thing, academia and industry players have talked about them for decades. Conceptual frameworks have been built around this concepts, and exciting ideas have come and go. For the last three decades, slowly but steady, Intelligent/Smart buildings have been slowly taking form.

Since the first definition of an intelligent building in the early 80's by the Intelligent Building Institution as a "one which integrates various systems to effectively manage resources in a coordinated mode to maximize: technical performance; investment and operating cost savings; flexibility" many new were developed according to the current technology available.

Smart Building is a concept in constant evolution, and the definitions have evolved importantly in the last decades expanding the definition and functionalities that smart buildings must have.

Figure 9 - Updated IB pyramid

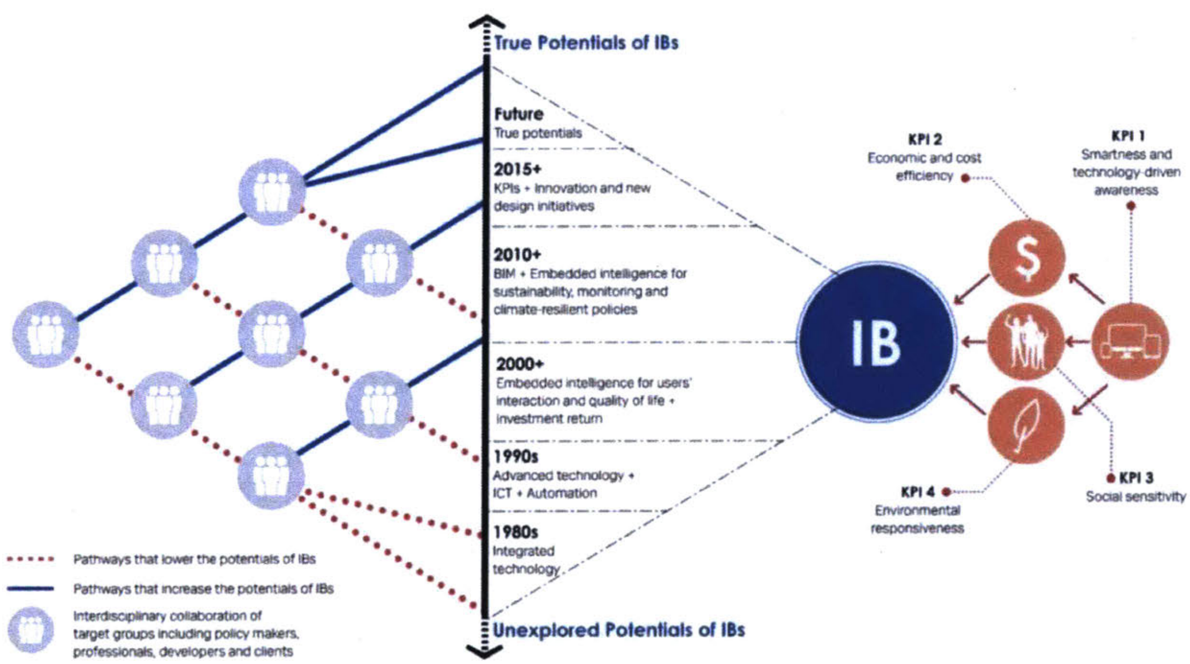


Source: (Ghaffarianhoseini et al., 2015) after (Harrison, 1999).

Nowadays, to be considered smart, buildings must "respond to all three components of systems, performances, and services and has to have the following components: a) Smartness and technology awareness, b) economic and cost efficiency, c) personal and social sensitivity and d) environmental responsiveness" (Ghaffarianhoseini et al., 2015). These components can be defined as follows:

- **Smartness and Technology awareness:** strategic use of cutting-edge technology to solve and create solutions that can be updated through time.
- **Economic and cost efficiency:** systems must take into account the whole life cycle and align to the investment strategy of the developer/investor.
- **Personal and social sensitivity:** solutions must be personalized and consider the expectations and requirements of all the occupiers and users, their well-being, satisfaction, and safety.
- **Environmental responsiveness:** design must be sustainable, promote renewable energy uses, energy efficient strategies, and conservation techniques.

Figure 10 - Evolutionary progression of Smart Buildings



Source: (Ghaffarianhoseini et al., 2015).

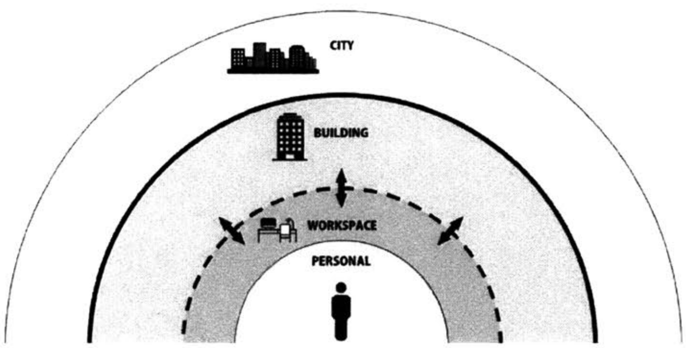
2.3. The new functionalities of Smart Buildings

Surely, Smart Buildings will enhance their operational functions by making them more efficient, but are there any new functionalities that we currently do not consider that will be added thanks to new technologies?

One clear opportunity for this new technology is the possibility to reduce the barrier that exists between the landlord and tenant relationship. New technologies that are pushing the boundaries of the definition of what a Smart Building is and its relationship with the disruption in the workplace, where tenants and landlords can collaborate to create a win-win relationship.

The workspace scene can be explained as several consecutive layers that altogether built the places where people work every day (**Figure 11**). Technology is distributed in these different layers. For example, HVAC Systems is infrastructure that operates at the building level to create a comfortable temperature for occupants, while smartphones operate on a more personal level helping us to have immediate access to different ways of communication.

Figure 11 - Layers of interaction



The personal and the workspace sphere are intrinsically connected, but technology and the disruption of the workspace have started to create more frequent interactions between these two layers and the Building infrastructure. Mainly thanks to IoT the possibilities of synergies and the new value that can be created from a closer interaction between these three layers have opened a great variety of opportunities for the real estate industry to reinvent itself.

The Internet of Things (IoT) has created a new dimension of building interaction and is the possibility to provide "things" the ability to communicate with other "things." However, what does this mean for the owner-occupier relationship? Until today, this relationship has limited to the lease space in exchange for rent. "Location, location, location" has been the motto for real estate and building owners have limited their tenant's interactions to only providing a physical location where occupiers can establish and operate their companies.

Nevertheless, how far do smart buildings extend? Are these IoT devices and new technologies reaching the building's components that are under the developer scope? Or, are these devices located more in the occupier's realm affecting the inner layers: Stuff and Space Plan?

Incremental value of Smart Buildings

3. Smart Buildings in the New York Office Market

As we have shown in previous chapters, technology is being used as a catalyst to improve the way we work and is changing not only how we work but also where and when we work. Technology is also helping us to improve communications between individuals and in more recent years communications between companies and service providers. For buildings, places were we spend must of our time; this means a new world of opportunities that open the doors to new alliances with unexpected partners that until were difficult to imagine.

Buildings in the world have now an opportunity to understand their users and give them information that can improve their daily routines. It is not surprising that forward-looking developers are already looking for partnerships with companies like Uber or Lyft. By letting these companies known how many people are in the building in real time, car-sharing companies can provide a better and faster service and the developer can claim that his building provides better commute infrastructure than their peers.

Strategic partnerships will start to appear also between landlords and tenants, and this could create even stronger relationships. From a financial perspective, the landlord will benefit since their tenant will be more inclined to stay loyal and keep leasing space in their portfolio because they will be paying for more than just space in a building, they will be paying for a whole package of services.

Developers around the world have started to study and understand the new relationships and opportunities that technology could open for them. In Boston, Lstar has partnered with GE to develop Union Point, a new SmartCity twenty minutes from Boston, that will be the first community scale development to incorporate multiple sensors and systems to manage the operations and services of the city. In Arizona, the news recently announced that Bill Gates invested $80 million in building a smart city in the desert, which will feature high-speed public wifi, high-tech manufacturing facilities and the infrastructure needed for autonomous cars and public transportation. These new trends shows that innovation is going beyond just sustainability, is now pushing to a new sort of structures, ones that are Smart, Connected and Green.

In New York, developers have also started to implement technology and sensors into their new developments. In this race, Related and Oxford Properties are building Hudson Yards. One of the most ambitious mix-use projects in New York, Hudson Yards stands out as one of "the most connected, measured, and technologically advanced digital district in the nation, with state-of-the-art infrastructure."(Bailey, 2017). Collaborating with New York University's Center for Urban Science and Cornell Tech, the development will share data to improve the daily experience of the users and the operation of the neighborhood.

However they are not alone, other innovations have been put in place by other developers around the city. Security and prevention have been a clear objective for the developers of the 1 and 4 World Trade Centers, who had used an advanced monitoring system to ensure the safety of their occupiers.

Sustainability and operation management systems have also been the target of disruptions, and some buildings have started to include Smart Systems like IBM Watson, which help to have predictive maintenance. Other innovations like High-Performance Windows, Smart Elevator Distpacht, Individual Thermostat controls, and Smart Facades, among many others, have started to appear as smart features offer by the developer to their tenants.

The prior published literature on the financial implications of innovation in real estate has mostly focused on Green Certifications (**Table 2** - Studies on Real Estate Innovation), and most of them have shown a positive relationship between environmental certifications and financial outcomes (Chegut et al., 2014). Although sustainability has been one of the most important recent innovations in the marketplace, for developers and investors is also important to understand the risk and value of other types of innovations.

As we pointed out in previous chapters, the scope promised of this innovations go far beyond just sustainability and have the potential to create new and exciting business opportunities for all the players in the marketplace.

This chapter investigates the dynamics behind the financial performance of New York's Smart, Connected and Green Buildings, measured ex-post by sales transactions and achieved rents over the 2013 to 2017 period.

4. Hedonic Technique: A Transaction-based methodology

Thanks to the increasing information available about the real estate market, nowadays we have sufficient transaction-base and lease data to analyze with more advanced techniques the dynamics of commercial real estate' prices given time, location, and other buildings characteristics. On of this techniques, the Repeat Sales Indices gives a reflection of the market conditions any given period. The other technique, the Hedonic model prices a product given the product's components. In this way, the hedonic model allows us to understand the drivers of the value of an asset as opposed to returns as experienced by the repeat sales model.

Repeated Sales Indices began using available appraisal information, and in the earlies 70's, the NCREIF appraisal-based index was the first commercial property index developed. The primary strength of this method is the reflection of capital gains or depreciation in the market (Chegut, 2013), giving you a reflection of the market conditions in any given period (Geltner & Fisher, 2007). Nevertheless, the method has several drawbacks. One of them is that the repeat sales methodology requires a significant amount of time for indexes to mature since they need a set of properties that have transacted multiple times. This method makes impossible to measure innovations in properties since information is limited.

Alternatively, hedonic methods mechanism enhance metro-level transaction-based index. The method relates individual product's components to the transacted price or rent. This way we can relate external characteristics of the building like location, time, age, renovation date, and internal components like installed network, operational systems used and amenities offered by the building and the weight they play on the final price of the sale transaction or the lease. The effectiveness of the methodology relies on the quality of the variables used to create the hedonic model and that this is available and abundant. Compared to repeated sales indices, hedonic models do not need repeated sales transactions since it uses the full cross-section of data and this makes this methodology ideal to analyze the effects of recent innovations in the marketplace.

Nevertheless, this method also has its limitations and are that these models are as good as the quality of the data used to derive them. In a dynamic market, like commercial real estate, maintain timely measures can be challenging and this can introduce noise to the model.

Data Collection and Methodology

For this study, we decided to use an integration of various databases with variables we are going to introduce in this chapter. We will also provide descriptive statistics of the data and an anticipated hypothesis about the premium rent and transaction prices of Smart Buildings. Finally, we are going to introduce the ex-post transaction-based hedonic model which will be the asset pricing methodology we are going to use for our analysis.

5. Data Sources

Firstly, for transaction and rent data, we are going to use Real Capital Analytics (RCA©) and Compstack databases, respectively, which will give us our models' dependent variable or measure of value. These two databases also provide us some of the basic hedonic variables that we will use on our analysis like spatial location, transportation quality, walkability score, transaction details, and buyer/tenant characteristics. Both companies gather data via a crowd-sourced model to gather lease and sale transactions data. Compstack in the rented area provides information of effective rents instead of asking rents. For accuracy, both platforms verify the information received with many different filters, so the published information is accurate and reliable.

To measure smart buildings we created three dummy variables that measure three characteristics that we think are what makes a building smart: smart amenities (innovative systems), connectivity and sustainability.

For sustainability, we used GBIG (Green Building Information Gateway) information available online, to match the buildings that currently are LEED certified projects. For connectivity, we used WiredScore database which gives certifications to buildings that can provide quality infrastructure for network connectivity to their tenants. Similar to LEED, WiredScore gives a score and certification depending on the level of digital connectivity that they provide, the certification analyses everything related to digital connectivity infrastructure, from the number of internet providers, the location and size of the telecommunication room to the readiness and access levels.

Since there is no currently a certification that let us identify smart amenities, we used MIT Innovation Lab research that helped us flag smart features that are currently installed in New York buildings recently renovated or developed[2]. The database of the Lab provides a comprehensive list of the smart features (See Chapter 2. currently in existence or those which developers have promised to install in the projects under construction. The primary reason of selecting Manhattan as the study market is the wide availability of data and the recognition of Manhattan as the premier Real Estate Market in the U.S. regarding capital market wealth, cross-border capital movement, global financial stability and financial market power.

6. Smart, Connected and Green

As we mentioned in the previous chapter, the definition of a smart building is a concept in constant evolution. So to currently identify what we consider a smart building in this study, we defined them as buildings that are:

- **Smart**: currently have installed one or more smart amenities that go beyond sustainability and aim to improve the ocuppier experience.
- **Connected**: buildings that provide the cutting-edge technology that let them provide premium digital connectivity.
- **Green**: buildings that use technology to make their operations more energy efficient.

These characteristics help us create different categories depending on the level of smartness. The smartest where the ones which had three out of the three characteristics and we named them as

[2] To identify Smart features we research buildings that had at least one of the level 2 and 3 technologies listed in the Smart Readiness Indicator for Buildings like: Smart facade, high-performance windows, biometric controls, smart dispatch elevators, high-efficient management systems, occupancy sensors, addressable light system, campus-wide or building optimization and coordination system, advance heating and cooling control systems, advance supply air flow systems, automatic windows blind controls, renewable energy systems on-site, energy grid systems, adaptive HVAC, etc. We found that the oldest buildings with these technologies were build or renovated from 2013 onwards. Therefore, we selected as our sample only transaction or leases in buildings built or renovated after 2013.
To identify these components in buildings we use marketing materials, information in the leasing and marketing buildings' websites, technology providers published case studies, GBIG Database for technology, etc.

"Green, Connected and Smart" buildings. Next, we label those buildings that only had two out of three characteristics ("Smart and Connected," "Smart and Green" and "Connected and Green"). Finally, the third level contains buildings with only one of the characteristics.

The treated sample contained all the observations that had at least one of the characteristics.

7. Descriptive Statistics

7.1. Rental Sample

Our rental sample contained 677 observations from which 223 leases are in a Smart category building (treated group) and 454 in a non-smart building (control group). We use Compstack's Manhattan transaction database from 2013 onwards as our base data source for both the treated and control group. Since IoT devices are new in the market, we track buildings which had implemented IoT devices and found that these buildings appeared until 2013, so we took this year as our reference to compare smart and non-smart buildings.

Compstack database contains 76 variables that range from buildings and lease contract characteristics, tenant profile, and market variables. From this database, we use 12 variables and the effective rent for each lease that became our dependent variable. The twelve variables were: submarket, lease commencement date, building age, renovation year, number of stories, building size, transaction type, term, transaction size, rent-free period, brokers involved and tenant industry.

Table 6 - Descriptive Statistics (Rent analysis)

		(a) Treated Group		**(b) Control Group**	
	Variable	Percentage	N	Percentage	N
	Observations				
Interest variable	**Smart Category**				
	Smart, Connected and Green (SCG)	1.30	3		
	Connected and Green (CG)	3.41	76		
	Smart (S)	9.00	20		
	Connected (C)	23.8	53		
	Green (G)	31.8	71		
Mar ket	**Submarket**				
	Chelsea	1.79	4	7.27	33

	Variable	(a) Treated Group Percentage	(a) Treated Group N	(b) Control Group Percentage	(b) Control Group N
	Observations				
	City Hall Insurance			4.19	19
	Columbus Circle	12.56	28		
	Financial District	8.52	19	11.23	51
	Gramercy Park Union Square	21.52	48	12.56	57
	Grand Central	17.94	40	4.63	21
	Hudson Square			3.74	17
	Hudson Yards	2.69	6	1.54	7
	Madison/Fifth Avenue	4.93	11	5.07	23
	Midtown Eastside	10.76	24	0.66	3
	Murray Hill	0.45	1	1.98	9
	NoHo Greenwich Village			1.76	8
	North Manhattan			0.66	3
	Park Avenue	0.45	1	8.15	37
	Penn Station			6.83	31
	Sixth Avenue	11.21	25	3.96	18
	SoHo			4.63	21
	Times Square			1.54	7
	Times Square South	0.90	2	15.42	70
	Tribeca			1.10	5
	Upper Eastside			0.66	3
	Upper Westside			1.54	7
	World Trade Center	6.28	14	0.88	4
	Lease Commencement Date				
	2013	22.87	51	19.38	88
	2014	28.70	64	31.06	141
	2015	22.87	51	27.97	127
	2016	21.97	49	20.26	92
	2017	2.24	5	0.88	4
	After 2017	1.35	3	0.44	2
Building characteristics	**Building Age**				
	Less than 30 years old	28.17	60	12.90	32
	30 – 60 years old	31.92	68	31.45	78
	60 to 90 years old	7.04	15	23.79	59
	More than 90 years old	32.86	70	31.85	79
	Renovation Year				
	2013	40.85	67	62.14	151
	2014	44.51	73	25.51	62
	2015			11.93	29
	2016	14.63	24	0.41	1
	Building Floors				
	15 Floors or less			19.12	48

		(a) Treated Group		(b) Control Group	
	Variable	Percentage	N	Percentage	N
	Observations				
	16 - 30 Floors	57.55	122	30.28	76
	31 - 45 Floors	32.08	68	39.04	98
	46 - 70 Floors	4.72	10	11.55	29
	More than 70 Floors	5.66	12		
	Building size				
	500,000 sqf. or less	53.02	114	40.39	103
	500,000 sqf. - 1,000,000 sqf.	18.60	40	34.90	89
	1,000,000 sqf. - 1,500,000 sqf.	11.16	24	12.55	32
	More than 1,500,000 sqf.	17.21	37	12.16	31
Tenant characteristics	**Tenant industry**				
	Finance	28.70	64	13.00	59
	Government			0.22	1
	Healthcare	3.14	7	3.96	18
	Media	7.62	17	3.30	15
	Non-Profit	0.90	2	1.10	5
	Service	25.56	57	20.26	92
	Technology	11.21	25	5.95	27
	Retail	1.35	3	4.41	20
	Other*	1.79	4	2.64	12
Lease characteristics	**Type of transaction**				
	Expansion	7.91	17	6.39	23
	Extension			0.83	3
	New Lease	83.72	180	82.50	297
	Early Renewal			0.28	1
	Renewal	7.91	17	9.17	33
	Renewal/Expansion	0.47	1	0.83	3
	Transaction size				
	Under 10,000 sqft.	46.64	104	60.35	274
	10,000 sqft. – 25,000 sqf.	24.22	54	24.01	109
	25,000 sqft. – 50,000 sqf.	13.45	30	9.03	41
	Over 50,000 sqft.	15.70	35	6.61	30
	Rent-free period				
	Less than 6 months	56.60	126	60.06	215
	6 – 12 months	22.79	49	27.93	100
	13 – 18 months	12.56	27	11.73	42
	19 – 24 months	6.05	13	0.28	1
	Lease Term				
	5 yrs or less	14.35	32	25.99	118
	6 – 10 years	38.12	85	27.09	123
	11 – 15 years	31.84	71	38.11	173
	16 – 20 years	13.90	31	7.71	35

Variable	(a) Treated Group Percentage	N	(b) Control Group Percentage	N
Observations				
More than 20 years	1.79	4	1.10	5
Broker Flag				
Landlord Broker	80.27	179	52.42	238
Tenant Broker	70.85	158	48.02	218

Note: Table 8 highlights the characteristics of the different variables employed as control variables in the asset pricing model including the variable of interest (Smart Category), and the independent variables including those related to hedonic, market, tenant and contract, for both the treated and the control group. *Includes real estate, education, entertainment, hospitality, fitness, etc.

Table 7 - Rents Descriptive Statistics (Mean and SD)

	(a) Treated Group				(b) Control Group			
Variable	Mean	Min	Max	N	Mean	Min	Max	N
SCG, CG, S, C, G	64.6 (24.3)	26	170.1	223	55.09 (32.9)	4.5	436.2	454
SCG	82.6 (4.6)	77.4	86.5	3				
CG	49.6 (8.0)	26	70.5	76				
S	78.9 (31.2)	51.2	170.1	20				
C	54.9 (14.7)	28.3	100.3	53				
G	83.31 (25.4)	36.9	155	71				
Building Size	847,002 (679,881)	107,865	2,600,000	215	700,034 (550,343)	11,572	2,239,000	255
Number of floors	32.37 (14.05)	17	92	212	30.5 (13.6)	4	67	251
Transaction Size	31,106 (55,197)	671	400,000	223	19,955 (52,658)	115	570,000	453
Free Rent Period	6.64 (5.1)	1	24	195	5.8 (3.8)	0.5	20	312
Lease Term (months)	102.7 (49.9)	12	252	223	92.9 (53.3)	12	396	454

Note: Table 7 highlights the characteristics of the different variables including the variable of interest (Smart Category), and the independent variables including those related to hedonic, market, tenant and contract, for both the treated and the control group. Standard deviation is in parenthesis.

7.2. Sales Sample

Our sales sample contained 129 observations from which 51 leases are in a Smart category building (treated group) and 78 in a non-smart building (control group). We use RCA© Manhattan transaction database from 2013 onwards as our base data source for both the treated and control group. For the same reasons, we use the same parameter than our rental samples; we only considered transaction closed 2013 onward.

RCA© database contains 253 variables that range from buildings and transaction characteristics, buyer and seller profile to market variables. From this database, we use 13 variables and the transaction price for each lease which became our dependent variable. The thirteen variables were: submarket, transaction date, building age, renovation year, number of stories, transaction size, buyer objective, transitscore, walkscore, information quality, type of transaction, type of investment and brokers involved.

Table 8 - Descriptive Statistics (Transactions analysis)

		(a) Treated Group		(b) Control Group	
	Variable	Percentage	N	Percentage	N
	Observations				
Interest variable	**Smart Category**				
	Smart, Connected and Green (SCG)	3.92	2		
	Connected and Green (CG)	11.76	6		
	Smart (S)	1.96	1		
	Connected (C)	66.67	34		
	Green (G)	15.69	8		
Market characteristics	**Submarket**				
	Downtown	23.53	12	29.49	23
	Midtown East	19.61	10	16.67	13
	Midtown South	19.61	10	15.38	12
	Midtown West	33.33	17	35.90	28
	Upper East Side	3.92	2	2.56	2
	Transaction Date				
	2013	7.84	4	16.67	13
	2014	17.65	9	10.26	8
	2015	43.14	22	33.33	26
	2016	25.49	13	38.46	30
	2017	5.88	3	1.28	1
Building characteristics	**Building Age**				
	Less than 30 years old	18.37	9	22.95	14
	30 – 60 years old	34.69	17	6.56	4
	60 to 90 years old	16.33	8	24.59	15
	More than 90 years old	30.61	15	45.90	28

	Variable	(a) Treated Group Percentage	(a) Treated Group N	(b) Control Group Percentage	(b) Control Group N
	Observations				
	Renovation Year				
	2013	30.95	13	40.00	20
	2014	35.71	15	30.00	15
	2015	23.81	10	26.00	13
	2016	9.52	4	4.00	2
	Building Floors				
	15 Floors or less	12.24	6	55.22	37
	16 - 30 Floors	57.14	28	32.84	22
	31 - 45 Floors	16.33	8	2.99	2
	46 - 70 Floors	14.29	7	5.97	4
	More than 70 Floors		0	2.99	2
	Building size				
	500,000 sqf. or less	62.75	32	67	67
	500,000 sqf. - 1,000,000 sqf.	13.73	7	4	4
	1,000,000 sqf. - 1,500,000 sqf.	3.92	2	4	4
	More than 1,500,000 sqf.	19.61	10	3	3
	WalkScore				
	Below average WalkScore (<94)			5.13	4
	Average WalkScore (94 – 97)			3.85	3
	Above average WalkScore (>97)	100	51	91.03	71
	TransitScore				
	Below average TransitScore (<94)	17.65	9	26.92	21
	Average TransitScore (94 – 97)				
	Above average TransitScore (>97)	82.35	42	73.08	57
Tenant characteristics	**Buyer Objective**				
	Condo Conversion			2.56	2
	Investment	90.20	46	74.36	58
	Occupancy	5.88	3	8.97	7
	Redevelopment	3.92	2	7.69	6
	Renovation			6.41	5
Lease characteristics	**Type of transaction**				
	Refinance	47.06	24	42.31	33
	Sale	52.94	27	57.69	45
	Type of investment				
	Core/Stabilized	68.63	35	58.97	46
	Occupancy	5.88	3	8.97	7
	Value-Add	25.49	13	32.05	25
	Information quality				
	Allocated	5.88	3	10.26	8
	Appraised	19.61	10	17.95	14
	Approximate	13.73	7	16.67	13

Variable	(a) Treated Group Percentage	N	(b) Control Group Percentage	N
Observations				
Confirmed	31.37	16	29.49	23
Estimated	15	15	23.08	18
Street talk			2.56	2
Broker Flag				
Seller Broker	3.92	2	10.26	8
Buyer Broker	35.29	18	41.03	32

Note: Table 8 highlights the characteristics of the different variables employed as control variables in the asset pricing model including the variable of interest (Smart Category), and the independent variables including those related to hedonic, market, tenant and contract, for both the treated and the control group. *Includes real estate, education, entertainment, hospitality, fitness, etc.

Table 9 - Transactions Descriptive Statistics (Mean and SD)

	(a) Treated Group				(b) Control Group			
Variable	Mean	Min	Max	N	Mean	Min	Max	N
SCG, CG, S, C, G	883.37 (492.3)	285.71	3,095.23	51	932.86 (693.88)	181.64	5,440.23	78
SCG	850.14 (0)	850.14	850.14	2				
CG	738.63 (135.21)	507.22	872.16	6				
S	285.71 (0)	285.71	285.71	1				
C	814.38 (329.05)	295.76	1,788.48	34				
G	1368.15 (920.14)	336.47	3,095.23	8				
Building Size	726,359 (780,645)	17,267	2,625,640	51	286,612 (458,707)	3,400	2,285,043	78
Number of floors	27.71 (14.06)	7	67	49	18.86 (17.18)	3	90	67
WalkScore	99.21 (0.96)	97	100	51	99 (1.31)	92	100	75

Note: Table 9 highlights the characteristics of the different variables including the variable of interest (Smart Category), and the independent variables including those related to hedonic, market, tenant and contract, for both the treated and the control group. Standard deviation is in parenthesis.

8. Methodology

We use the MIT Real Estate Innovation Lab NYC Wide Data database to estimate a semi-log equation relating the office per net rent square feet and selling price per net square feet to the hedonic characteristics of a building:

$$\log P_i = \alpha + \beta X_i + \delta g_i + \varepsilon_i \qquad (1)$$

where the dependent variable is the logarithm of the rental or selling price per net square meter P_i in commercial office buildings i. X_i is a vector of hedonic characteristics (e.g., age, stories, size, public transportation accesability, etc.), rental contract features (e.g., lease length and rent-free period), market signals (days on market), investors types, and macro-economic conditions (e.g. quarterly time dummies) of buildings i, and g_i is vector of dummy variable with a value of 1 if building i is Smart, Connected and Green, Smart and Connected, Smart and Green, Connected and Green, Smart, Connected or Green and zero otherwise. α, β and δ are estimated coeficients and ε_i is an error term.

Results

9. Smart Buildings and Rental Rates

Table 10 presents the regression results for the rental sample, relating the logarithm of rent per net square feet of commercial office space to a set of hedonic characteristics, neighborhood controls, and contract features. These specifications explain fifty percent of the variation in the logarithm of rents per net square feet with an adjusted R-squared ranging from 46 to 47 percent. Since the different Smart categories are highly correlated with each other, we measure the results separately. Column (1) to (5) measures the effects of Smart, Connected, Green, Connected and Green, and Smart, Connected and Green buildings respectively. We report the results for the hedonic specification relating office rents to the hedonic characteristics, i.e., building size, building renovation year, rental size, lease type, contract length, free-rent period, broker presence, sublease flag, time-fixed effects, and location-fixed effects.

For all buildings the coefficient of lease extensions is negative and significant: tenants looking for an extension can expect lower rental rates per net square feet. Relative to the leased area spaces of less than 10,000sqft., areas of more than that will transact at a 10 percent discount. Finally, longer leases (i.e., leases from 10 years onwards) will pay higher net rent per square feet compared to leases of five years or less.

Keeping constant the observable characteristics, three out of five of the smart categories are positive and significant. Smart only properties command a 37 percent premium, Green properties a 20 percent and Smart, Connected and Green a 37 percent. Surprisingly, connected buildings show a small discount but insignificant.

Table 10 - The impact of Smart, Connected and Green Buildings on Effective Rents

VARIABLES	(1) S	(2) C	(3) G	(5) SCG
Smart Category				
Smart	0.375***			
	[0.099]			
Connected		-0.002		
		[0.058]		
Green			0.207***	
			[0.064]	
Connected and Green				
Smart, Connected and Green				0.377**
				[0.148]
LOCATION CHARACTERISTICS				
Neighborhoods (Base Case: Park Avenue)				
Chelsea	-0.431***	-0.455***	-0.466***	-0.436***
	[0.080]	[0.082]	[0.080]	[0.084]
City Hall Insurance	-0.459***	-0.484***	-0.494***	-0.477***
	[0.144]	[0.144]	[0.144]	[0.145]
Columbus Circle	0.118	0.066	-0.183*	0.099
	[0.112]	[0.112]	[0.106]	[0.119]
Financial District	-0.621***	-0.652***	-0.652***	-0.658***
	[0.066]	[0.067]	[0.068]	[0.066]
Gramercy Park Union Square	-0.174***	-0.196***	-0.226***	-0.182***
	[0.066]	[0.068]	[0.064]	[0.069]
Grand Central	-0.365***	-0.392***	-0.395***	-0.405***
	[0.071]	[0.071]	[0.071]	[0.069]
Hudson Square	0.008	-0.014	-0.013	0.011
	[0.104]	[0.104]	[0.104]	[0.106]
Hudson Yards	-0.339***	-0.264**	-0.257*	-0.226
	[0.124]	[0.132]	[0.133]	[0.138]
Madison/Fifth Avenue	0.236***	0.215***	0.130*	0.215***
	[0.080]	[0.081]	[0.072]	[0.079]
Midtown Eastside	-0.235***	-0.262***	-0.269***	-0.250***
	[0.067]	[0.086]	[0.067]	[0.069]
Murray Hill	-0.597***	-0.613***	-0.616***	-0.594***
	[0.111]	[0.113]	[0.113]	[0.115]
NoHo Greenwich Village	-0.435***	-0.454***	-0.464***	-0.429***
	[0.102]	[0.102]	[0.101]	[0.105]
North Manhattan	-0.785***	-0.792***	-0.799***	-0.760***
	[0.146]	[0.135]	[0.127]	[0.141]
Penn Station	-0.452***	-0.478***	-0.493***	-0.463***
	[0.100]	[0.101]	[0.098]	[0.102]
Sixth Avenue	-0.156	-0.172*	-0.250**	-0.177*
	[0.097]	[0.098]	[0.114]	[0.099]
SoHo	-0.201**	-0.222***	-0.234***	-0.205**
	[0.083]	[0.083]	[0.083]	[0.086]
Times Square	-0.705***	-0.725***	-0.731***	-0.709***
	[0.249]	[0.249]	[0.248]	[0.249]
Times Square South	-0.452***	-0.489***	-0.491***	-0.475***
	[0.082]	[0.082]	[0.081]	[0.083]

VARIABLES	(1) S	(2) C	(3) G	(5) SCG
Tribeca	-0.299**	-0.321***	-0.319***	-0.308***
	[0.119]	[0.118]	[0.119]	[0.117]
Upper Eastside	-0.350	-0.370	-0.388*	-0.352
	[0.227]	[0.229]	[0.228]	[0.230]
Upper Westside	-0.344	-0.363	-0.375	-0.347
	[0.257]	[0.257]	[0.258]	[0.258]
World Trade Center	-0.695***	-0.448***	-0.444***	-0.417***
	[0.101]	[0.097]	[0.097]	[0.101]
Lease Commencement Date (Base case: Lease Commencement 2013)				
Lease Commencement 2014	0.090***	0.090***	0.079**	0.091***
	[0.032]	[0.032]	[0.032]	[0.032]
Lease Commencement 2015	0.142***	0.141***	0.133***	0.141***
	[0.035]	[0.035]	[0.036]	[0.035]
Lease Commencement 2016	0.242***	0.243***	0.242***	0.236***
	[0.038]	[0.038]	[0.037]	[0.038]
Lease Commencement 2017	0.185	0.171	0.161	0.163
	[0.130]	[0.128]	[0.130]	[0.128]
Lease C. after 2017	0.299***	0.314***	0.331***	0.308***
	[0.109]	[0.109]	[0.103]	[0.112]
BUILDING QUALITY CHARACTERISTICS				
Total size of the building (Base Case: Over 1,500,000sqf)				
500,000sqf or less	-0.014	0.014	0.048	-0.016
	[0.069]	[0.067]	[0.063]	[0.075]
500,000sqf - 1,000,000sqf	-0.013	0.019	0.058	0.008
	[0.073]	[0.072]	[0.069]	[0.074]
1,000,000sqf - 1,500,000sqf	0.109	0.161*	0.185**	0.138
	[0.086]	[0.084]	[0.081]	[0.088]
Building Renovation Year (Base Case: Renovation 2016)				
Renovated 2013	0.105	0.145	0.156	0.099
	[0.099]	[0.097]	[0.095]	[0.109]
Renovated 2014	0.004	0.022	-0.003	0.013
	[0.046]	[0.046]	[0.047]	[0.047]
Renovated 2015	0.173***	0.195***	0.155**	0.192***
	[0.056]	[0.055]	[0.061]	[0.056]
LEASE CONTRACT CHARACTERISTICS				
Transaction Size (Base Case: Under 10,000sqf.)				
10,000sqf - 25,000sqf	-0.099***	-0.105***	-0.108***	-0.109***
	[0.035]	[0.035]	[0.034]	[0.035]
25,000sqf - 50,000sqf	-0.139**	-0.155**	-0.163**	-0.170**
	[0.066]	[0.066]	[0.065]	[0.067]
Over 50,000sqf	-0.116*	-0.118*	-0.145**	-0.127*
	[0.064]	[0.066]	[0.066]	[0.067]
Lease Type (Base Case: New Lease)				
Lease Expansion	0.002	-0.007	0.009	-0.003
	[0.035]	[0.036]	[0.037]	[0.036]
Lease Extension	-0.317***	-0.313***	-0.307***	-0.314***
	[0.104]	[0.101]	[0.109]	[0.102]
Lease Renewal	0.016	0.011	0.025	0.015
	[0.044]	[0.045]	[0.046]	[0.045]
Lease Renewal/Expansion	0.036	0.036	0.073	0.037
	[0.131]	[0.136]	[0.136]	[0.135]
Lease Term (Base Case: 5 years or less)				
Lease term 6 - 10yrs	0.089**	0.088**	0.082**	0.086**
	[0.043]	[0.043]	[0.041]	[0.042]
Lease term 11 - 15yrs	0.212***	0.210***	0.205***	0.210***

VARIABLES	(1) S	(2) C	(3) G	(5) SCG
	[0.060]	[0.060]	[0.060]	[0.060]
Lease term 16 - 20yrs	0.344***	0.355***	0.344***	0.359***
	[0.079]	[0.079]	[0.078]	[0.079]
Lease term 21 - 25yrs	0.401***	0.352***	0.332***	0.352***
	[0.101]	[0.111]	[0.110]	[0.110]
Free-rent Period (Base Case: Less than 6 months)				
6 - 12 months free	0.068**	0.073**	0.070**	0.071**
	[0.034]	[0.034]	[0.033]	[0.034]
13 - 18 months free	0.029	0.039	0.049	0.030
	[0.046]	[0.046]	[0.047]	[0.045]
19 - 24 months free	-0.044	0.084	0.070	0.096
	[0.105]	[0.115]	[0.113]	[0.116]
Sublease				
Sublease	-0.065	-0.062	-0.060	-0.065
(1 = yes)	[0.061]	[0.061]	[0.061]	[0.062]
Broker Presence				
Landlord broker	0.042	0.042	0.043	0.048
(1 = yes)	[0.047]	[0.047]	[0.047]	[0.048]
Tenant Broker	-0.006	-0.009	-0.008	-0.016
(1 = yes)	[0.037]	[0.038]	[0.037]	[0.039]
Constant	3.963***	3.944***	3.950***	3.975***
	[0.083]	[0.083]	[0.083]	[0.087]
Observations	677	677	677	677
R-squared	0.507	0.500	0.509	0.503
F Adj R2	0.47	0.46	0.47	0.46

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

10. Smart Buildings and Transaction Prices

Table 11 presents the regression results for the sales sample, relating the logarithm sales price per net square feet of commercial office space to a set of hedonic characteristics, neighborhood controls, investor type and transaction features. These specifications explain twenty-six to twenty-nine percent of the variation in the logarithm of sale prices per net square feet with an adjusted R-squared ranging from eight to thirteen percent. Since the different Smart categories are highly correlated with each other, we measure the results separately. Column (1) to (5) measures the effects of Smart, Connected, Green, Connected and Green, and Smart, Connected and Green buildings respectively. We report the propensity-weighted results for the hedonic specification relating office rents to the hedonic characteristics, i.e., building size, building renovation year, transaction size, buyer objective, number of floors transaction, broker presence, time-fixed effects, and location-fixed effects.

In this analysis, the sample contains too few observations for the Smart Category, and the results of this analysis are preliminary until further observations of smart building transactions become available.

For all categories the coefficient of condo conversion is positive and significant: buyers who are looking to convert old buildings to condos are willing to pay a premium. Relative to the Midtown West, properties in the Upper East Side will transact at a 90 percent premium. Finally, taller buildings (i.e., buildings of more than 70 floors) will transact at a premium.

Keeping constant the observable characteristics, only Smart, Connected and Green show a positive and significant coefficient, transacting at a 44 percent premium. Surprisingly, Connected properties transacted at a 120 percent discount, it is essential to recall that we only have one observation of a Smart building transaction, so the result is not relevant. Further explanation of the Connected variable can be found on the Appendix.

Table 11 - The impact of Smart, Connected and Green Buildings on Transaction prices

VARIABLES	(1) S	(2) C	(3) G	(5) SCG
Smart Category				
Smart	-1.206***			
	[0.226]			
Connected		-0.050		
		[0.103]		
Green			0.408	
			[0.252]	
Smart, Connected and Green				0.442**
				[0.214]
LOCATION CHARACTERISTICS				
Neighborhoods (Base Case: Midtown West)				
Downtown	-0.085	-0.048	-0.049	-0.043
	[0.145]	[0.146]	[0.146]	[0.149]
Midtown East	0.157	0.201	0.214	0.208
	[0.165]	[0.165]	[0.164]	[0.167]
Midtown South	0.214*	0.254**	0.246**	0.270**
	[0.116]	[0.116]	[0.118]	[0.122]
Upper East Side	0.976***	0.997***	0.827***	0.996***
	[0.359]	[0.364]	[0.306]	[0.363]
Transaction Date (Base case: Transaction 2013)				
Transaction 2014	0.018	0.031	0.075	-0.028
	[0.198]	[0.199]	[0.200]	[0.202]
Transaction 2015	0.200	0.193	0.195	0.180
	[0.189]	[0.197]	[0.195]	[0.191]
Transaction 2016	0.258	0.282	0.334*	0.274
	[0.181]	[0.186]	[0.182]	[0.184]
Transaction 2017	0.170	0.216	0.253	0.187
	[0.271]	[0.278]	[0.266]	[0.277]
BUILDING QUALITY CHARACTERISTICS				
WalkScore (Base Case: Above average WalkScore)				
Below average WalkScore	0.044	0.044	0.077	0.053
	[0.295]	[0.295]	[0.287]	[0.288]
Average WalkScore	-0.417**	-0.436**	-0.335	-0.385*

VARIABLES	(1) S	(2) C	(3) G	(5) SCG
	[0.199]	[0.196]	[0.202]	[0.200]
TransitScore (Base Case: Above average TransitScore)				
Below average TransitScore	-0.076	-0.088	-0.084	-0.078
	[0.128]	[0.129]	[0.123]	[0.133]
TRANSACTION CHARACTERISTICS				
Buyer Objective (Base Case: Occupancy)				
Condo Conversion	0.784**	0.780**	0.775**	0.794**
	[0.315]	[0.307]	[0.311]	[0.315]
Redevelopment	-0.028	-0.021	-0.038	-0.016
	[0.297]	[0.285]	[0.287]	[0.298]
Investment	0.050	0.063	0.051	0.048
	[0.263]	[0.260]	[0.261]	[0.266]
Renovation	-0.103	-0.033	0.013	-0.038
	[0.335]	[0.345]	[0.345]	[0.350]
Transaction Size (Base Case: Over 1,500,000sqf)				
500,000sqf or less	-0.257	-0.061	0.036	-0.064
	[0.194]	[0.255]	[0.230]	[0.253]
500,000sqf - 1,000,000sqf	-0.367*	-0.175	-0.134	-0.170
	[0.211]	[0.265]	[0.232]	[0.266]
1,000,000sqf - 1,500,000sqf	-0.383	-0.195	-0.102	-0.165
	[0.352]	[0.388]	[0.372]	[0.383]
Total number of floors transacted (Base Case: 31 -45 Floors)				
15 Floors or less	0.083	0.056	0.062	0.112
	[0.152]	[0.151]	[0.148]	[0.156]
16 - 30 Floors	-0.006	-0.024	-0.065	0.029
	[0.138]	[0.137]	[0.136]	[0.150]
46 - 70 Floors	-0.128	0.018	-0.000	0.061
	[0.209]	[0.232]	[0.205]	[0.238]
More than 70 Floors	0.738**	0.804**	0.732**	0.814**
	[0.335]	[0.334]	[0.331]	[0.330]
Broker Presence				
Buyer Broker	-0.030	-0.004	0.018	0.003
(1 = yes)	[0.091]	[0.092]	[0.090]	[0.093]
Seller Broker	0.421	0.396	0.400	0.400
(1 = yes)	[0.318]	[0.312]	[0.317]	[0.316]
Constant	6.616***	6.394***	6.264***	6.347***
	[0.382]	[0.422]	[0.402]	[0.427]
Observations	129	129	129	129
R-squared	0.297	0.267	0.289	0.274
F Adj R2	0.13	0.089	0.12	0.097

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Discussion and Conclusions

Nowadays, our structures have evolved to fulfill more complex functionalities. Buildings' functionalities have expanded to more than just sheltering. Thanks to the level of comfort and advanced functionalities that we can have in a building, today humans spend nearly 90% of their time living indoors (Klepeis et al., 2001). We can say that "Our Buildings have become a comprehensive life-support mechanism(E. Allen, 2005)."

Thanks to IoT devices, we have now the possibility to measure and analyze the activity that occurs inside our structures, and this makes our approach to space distinct. Occupiers can measure a new dimension: productivity. Companies are not focused on location only anymore but now they look for more productive and efficient areas, and Smart buildings rise as a possible answer to this new requirement.

Smart Buildings will continue to be a concept in constant evolution. New technologies will push the definition and functionalities that a smart building can achieve, but today, thanks to the technology available, developers have a whole new world of opportunities in front of them that goes beyond sustainability and operationally efficient systems.

One clear opportunity for this new technology is the possibility to reduce the barrier that exists in the landlord-tenant relationship. New technologies are pushing the boundaries of the definition of what a Smart Building is and its relationship with the disruption in the workplace. Because of this, nowadays, to be considered smart, buildings must "respond to all three components of systems, performances, and services and have to have the following components: a) Smartness and technology awareness, b) economic and cost efficiency, c) personal and social sensitivity and d) environmental responsiveness" (Ghaffarianhoseini et al., 2015).

Nevertheless, the results of this analysis are limited, mainly because institutional investors have not been the leading promoters of these technologies. While corporate users have been exploring the benefits that these technologies can bring to their spaces and offices, and have been one of the main employers of new IoT devices. Developers have just started to explore and invest in these type of innovations. As result, evidence that suggests widespread institutional investment will always lag behind. In this way, any studies that point towards productivity gains or enhanced benefits to users should be considered by institutional investors. However, institutional investors are least likely to take up this type of innovation on their spaces as enhancing the productivity of tenants rather than their employees poses a problem of split incentives, where the gains go to the occupeirs rather than the operators. This crucial factor is at the core of why innovation in the built environment stagnates.

Although innovation research has data limitations, we documented that those developers or owners that are offering a more integrated solution in their buildings (i.e., Smart, Connected and Green buildings) have achieved a considerable 37 percent premium in rents and 44 percent premium in transaction prices, relative to non-Smart, Connected or Green buildings in the same neighborhood and over the same time period of 2013 to 2017.

Our study was a first step in trying to identify and classify what a smart building is. Nevertheless, the more these technologies advance, the higher the need for a special certification that will help us identify with certainty those buildings that are offering smart and efficient solutions to their clients. WiredScore has started to offer certification on the digital connectivity level that a building offers, and we expect in the future a certification that will also focus in system compatibility so tenants can talk and interact with building's system. Of course, Smart, Connected and Green buildings may reflect increased construction, renovation and operation costs. Today, there is no evidence of the marginal cost and operational expenses of this type of buildings and further research on this topic may provide a better understanding of the ROI related to investments in smart buildings.

Lastly, the results of this study show that first movers in this category are potentially realizing a premium that is much higher than average, nevertheless it is still unclear if these benefits surpass the costs that it takes to build them. Also, there is anecdotal evidence of developers getting other sources of income or even creating new products and services for their tenants thanks to these innovations. Further study about these new interactions could provide better insight on the new operations and opportunities of these new structures. In the end, complementing this research with studies in both the new opportunities of smart buildings as well as their costs will help us start to unravel the real value of Smart, Green and Connected Buildings.

References

Allen, E. (2005). *How buildings work: The natural order of architecture* (3rd ed.). Oxford; New York: Oxford University Press.

Allen, J. G., MacNaughton, P., Satish, U., Santanam, S., Vallarino, J., & Spengler, J. D. (2016). Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: A controlled exposure study of green and conventional office environments. *Environmental Health Perspectives*, *124*(6), 805–812.

Allen, T. J. (1984). *Managing the flow of technology: technology transfer and the dissemination of technological information within the R&D organization.* Cambridge, Mass.: MIT Press, 1984, c1977.

Allen, T. J., & Henn, G. (2007). *The organization and architecture of innovation: managing the flow of technology.* Amsterdam; Boston: Butterworth-Heinemann, c2007.

Apgar IV, M. (1998, May). The Alternative Workplace: changing where and how people work. *Harvard Business Review*, *76*(3), 121–136.

Bahrampour, T. (2017, May 25). Cities growing more slowly than suburbs for the first time in six years - The Washington Post. *The Washington Post.*

Bailey, S. (2017). Stephen M. Ross to Architects: Drop Your Egos. *Surface Magazine - Surfacemag.com.*

Brand, S. (1994). *How buildings learn: what happens after they're built.* New York, NY: Viking.

Brennan, A., Chugh, J. S., & Kline, T. (2002). Traditional versus open office design: A Longitudinal Field Study. *Environment and Behavior*, *34*(3), 279–299.

CBRE Research. (2017). *Global: Occupier Survey Report 2017.*

Chegut, A. (2013). *Innovation in Commercial Real Estate (Doctoral Dissertation).* Maastricht University School of Business and Economics.

Chegut, A., Eichholtz, P., & Kok, N. (2014). Supply, Demand and the Value of Green Buildings. *Urban Studies*, *51*(1), 22–43.

Claudel, M., Massaro, E., Santi, P., Murray, F., & Ratti, C. (2017). An exploration of collaborative scientific production at MIT through spatial organization and institutional affiliation. *PLoS ONE, 12 (6)*, e0179334.

Collins, E. G. C. (1986, January). A company without offices. *Harvard Business Review, 64*(1), 127–136.

Cortright, J. (2017, January). Flood tide–not ebb tide–for young adults in cities. *Cityobservatory.org.*

Davenport, T. H., Thomas, R. J., & Cantrell, S. (2002). The Mysterious Art and Science of Knoledge-Worker Performance. *MIT Sloan Management Review, 44*(1).

Devine, A., & Kok, N. (2015). Green Certification and Building Performance: Implications for Tangibles and Intangibles. *Journal of Portfolio Management, 41*(6).

Devine, A., Steiner, E., & YYnder, E. (2017). *Decomposing the Value Effects of Sustainable Investment: International Evidence. SSRN Electronic Journal.*

Eichholtz, P., Kok, N. N., Quigley, J. M., Guma, A., Gyourko, J., Kahn, M., … Wolfram, C. (2010). Doing Well by Doing Good? Green Office Buildings. *American Economic Review, 100*(5), 2492–2509.

Eichholtz, P., Kok, N., & Yonder, E. (2012). Portfolio greenness and the financial performance of REITs. *Journal of International Money and Finance, 31*(International Real Estate Securities), 1911–1929.

Fuerst, F. (2015). The Financial Rewards of Sustainability: A Global Performance Study of Real Estate Investment Trusts. *SSRN Electronic Journal*, 22.

Fuerst, F., & McAllister, P. (2011). Green Noise or Green Value? Measuring the Effects of Environmental Certification on Office Values. *Real Estate Economics, 39*(1), 45–69.

G. Miller, N. (2014). Workplace trends in office space: implications for future office demand. *Journal of Corporate Real Estate, 16*(3), 159–181.

Geltner, D., & Fisher, J. (2007). Pricing and Index Considerations in Commercial Real Estate Derivatives. *Journal of Portfolio Management, 33*, 99–118.

Geltner, D., Miller, N. G., Clayton, J., & Eichholtz, P. (2014). *Commercial real estate: analysis and investments* (3e.). Mason, OH: OnCourse Learning.

Geltner, D., Moser, L., & Minne, A. van de. (2017). The Effect of Green Retrofitting on US Office Properties: An Investment Perspective. *SSRN Electronic Journal.*

Ghaffarianhoseini, A., Berardi, U., AlWaer, H., Chang, S., Halawa, E., Ghaffarianhoseini, A., & Clements-Croome, D. (2015). What is an intelligent building? Analysis of recent interpretations from an international perspective. *Architectural Science Review, 8628*(October), 1–20.

Harrison, A. (1999). Towards the Intelligent City. *Intelligent and Responsive Buildings, CIB Working Commission WO98, 1st International Congress, Bruges, Belgium*, 175–183.

Hoos, I. R. (1960, July). When the Computer Takes Over the Office. *Harvard Business Review, 38*(4), 102–112.

JLL. (2016). Chicago's suburban migration interactive map (http://www.jll.com/chicago/en-us/research/suburban-migration).

Johansen, R. (1989). Groupwise and collaborative systems-a big picture view. In *IEEE Global Telecommunications Conference, 1989, and Exhibition. 'Communications Technology for the 1990s and Beyond* (pp. 1217–1220). IEEE.

John, S. P., & Puri, Z. (2017). *Financial impact of workplace performance on effective rents: a study of the Manhattan office market.*

Massachusetts Institute of Technology.

Kang, S., Ou, D., & Mak, C. M. (2017). The impact of indoor environmental quality on work productivity in university open-plan research offices. *Building and Environment*, *124*, 78–89.

Kats, G. H. (2003). *Green Building Costs and Financial Benefits*. Boston, MA.

Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., … Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Analysis and Environmental Epidemiology*, *11*(3), 231–252.

Kok, N., & Jennen, M. (2012). The impact of energy labels and accessibility on office rents. *Energy Policy*, *46*(Supplement C), 489–497.

Miller, N., Pogue, D., Saville, J., & Tu, C. (2010). The Operations and Management of Green Buildings in the United States. *Journal of Sustainable Real Estate*, *2*(1), 51–66.

Miller, N., Spivey, J., & Florance, A. (2008). Does Green Pay Off? *Journal of Real Estate Portfolio Management*, *14*(4), 385–399.

Moreland, J. B. (1989). Speech privacy evaluations in open-plan offices using the articulation index. *Noise Control Engineering Journal*, *33*(1), 22–32.

Morgan Stanley Insititute for Sustainable Investing. (2016). *Bricks, Mortar and Carbon How Sustainable Buildings Drive Real Estate Value.*

Myers, D. (2016). Peak Millennials: Three Reinforcing Cycles That Amplify the Rise and Fall of Urban Concentration by Millennials. *Housing Policy Debate*, *26*(6), 928–47.

Newell, G., McFarlane, J., & Kok, N. (2011). *Building Better Returns: A Study of the Financial Performance of Green Office Buildings in Australia. Australian Property Institute.*

Oldham, G. R., & Brass, D. J. (1979). Employee Reactions to an Open-Plan Office: A Naturally Occurring Quasi-Experiment. *Administrative Science Quarterly*, *24*(2), 267–284.

Poppel, H. L. (1982, November). Who needs the office of the future? *Harvard Business Review*, *60*(6), 146.

Sailer, K. (2007). Movement in workplace environments - Configurational or programmed? *Proceedings from the 6th International Space Syntax Symposium.*

Shiga, A. J. M. (1997). *Exploration of telecommuting and real estate demand ramifications: a comparison and contrast of various methodologies*. Massachusetts Institute of Technology.

Stone, P. J., & Luchetti, R. (1985, March). Your office is where you are. *Harvard Business Review*, *63*(2), 102–117.

Terrapin. (2014). *14 patterns of biophilic design.*

Timothy, D. P. (1995). *Urban labor markets and commuting*. Massachusetts Institute of Technology.

Timothy, D., & Wheaton, W. C. (2001). Intra-Urban Wage Variation, Employment Location, and Commuting Times. *Urban Economics*, *50*, 338–366.

Torto, R., Wheaton, W., & Southard, J. (1998). The office market pendulum. *Mortgage Banking*, *58*(4), 87.

Waber, B. N. (2011). *Understanding the Link Between Changes in Social Support and Changes in Outcomes with the Sociometric Badge*. Massachusetts Institute of Technology.

Wheaton, W. C. (1996). *Telecommunications technology and real estate: some perspective.* Cambridge, MA: Massachusetts Institute of Technology.

Wiley, J. A., Benefield, J. D., & Johnson, K. H. (2010). Green Design and the Market for Commercial Office Space. *The Journal of Real Estate Finance and Economics*, *41*(2), 228–243.

Appendixes

11. Number of buildings represented in the study

As pointed in the conclusions the results of our study are limited, mainly because the scarce of building represented in the sample. Since the adoption of new technologies has faced pushback from developers and the approach to innovation has been cautious and slow, the represented sample of buildings that are Smart, Green and Connected is limited.

In the following tables (**Table 12** and **Table 13**) we showed the number of buildings and their neighborhood distributions.

Table 12 - Number of buildings represented by neighborhood and Smart Category

	(a) Treated Group					(b) Control Group	Total
	SCG	CG	S	C	G	Control	
Chelsea				2		19	**21**
City Hall Insurance						9	**9**
Columbus Circle					1		**1**
Financial District		1				4	**5**
Gramercy Park Union Square		1		3	1	28	**33**
Grand Central	1	1				6	**8**
Hudson Square						5	**5**
Hudson Yards			2			4	**6**
Madison/Fifth Avenue					1	3	**4**
Midtown Eastside				1		3	**4**
Murray Hill				1		8	**9**
NoHo Greenwich Village						6	**6**

	(a) Treated Group					(b) Control Group	Total
	SCG	CG	S	C	G	Control	
North Manhattan						3	**3**
Park Avenue			1			5	**6**
Penn Station						6	**6**
Sixth Avenue		1			1	3	**5**
SoHo						16	**16**
Times Square						4	**4**
Times Square South				1		17	**18**
Tribeca						3	**3**
Upper Eastside						3	**3**
Upper Westside						6	**6**
World Trade Center			2	1		3	**6**
Total	**1**	**4**	**5**	**9**	**4**	**164**	**187**

Table 13 - Number of observations represented by neighborhood and Smart Category

	(a) Treated Group					(b) Control Group	Total
	SCG	CG	S	C	G	Control	
Chelsea				4		33	**37**
City Hall Insurance						19	**19**
Columbus Circle					28		**28**
Financial District		19				51	**70**
Gramercy Park Union Square		15		21	12	57	**105**
Grand Central	3	37				21	**61**
Hudson Square						17	**17**
Hudson Yards			6			7	**13**
Madison/Fifth Avenue					11	23	**34**
Midtown Eastside				24		3	**27**
Murray Hill				1		9	**10**
NoHo Greenwich Village						8	**8**
North Manhattan						3	**3**
Park Avenue			1			37	**38**
Penn Station						31	**31**
Sixth Avenue		5			20	18	**43**
SoHo						21	**21**
Times Square						7	**7**
Times Square South				2		70	**72**
Tribeca						5	**5**
Upper Eastside						3	**3**
Upper Westside						7	**7**
World Trade Center			13	1		4	**18**
Total	**3**	**76**	**20**	**53**	**71**	**454**	**677**

Is important to appreciate that although we have 677 observations, these observations only represent 187 buildings. For our treated sample we have 223 observations that represent 23 buildings. This distribution of observations under a small sample of buildings can introduce noise to our analysis.

Future studies will have more data available since smart, connected and green buildings will become a more common practice.

12. The connected variable

Table 14 shows the hedonic model for all the observations that are WiredScore certificated. The effect of this variable, although not statistically significant, shows that this vaiable is a statistical zero. This could be because likely all the buildings that were built or renovated after 2013 are fiber-lit, meaning that all the buildings in the sample are connected. Thus, the differenciator of being certified for being digital connected may not nesserarily differntiate new products. Our hypothesis is that new buildings in the market are all connected, and connectivity is a standard product now.

To confirm this a further study that identify the buildings that are fiber-lit and does who are not is needed.

Table 14 - The impact of Connected on Effective Rents

VARIABLES	(1) (1)	(2) (2)	(3) (3)	(4) (4)	(5) (5)
Connected (WiredScore Certificated)	-0.014	-0.012	-0.033	-0.042	0.032
	[0.038]	[0.034]	[0.052]	[0.052]	[0.038]
LOCATION CHARACTERISTICS					
Neighborhoods (Base Case: Midtown West)					
Chelsea	-0.405***	-0.360***	-0.399***	-0.372***	-0.294***
	[0.075]	[0.069]	[0.121]	[0.127]	[0.101]
City Hall Insurance	-0.474***	-0.444***	-0.406**	-0.326*	-0.240
	[0.146]	[0.142]	[0.186]	[0.195]	[0.158]
Columbus Circle	0.233***	0.238***	-0.023	-0.053	-0.034
	[0.062]	[0.058]	[0.145]	[0.144]	[0.126]
Financial District	-0.472***	-0.464***	-0.505***	-0.447***	-0.511***
	[0.061]	[0.053]	[0.085]	[0.094]	[0.056]
Gramercy Park Union Square	-0.149**	-0.147***	-0.176	-0.133	-0.017
	[0.062]	[0.057]	[0.119]	[0.122]	[0.096]
Grand Central	-0.258***	-0.234***	-0.256**	-0.218*	-0.185*
	[0.068]	[0.061]	[0.122]	[0.126]	[0.097]
Hudson Square	0.113	0.079	0.110	0.147	0.229*
	[0.107]	[0.109]	[0.152]	[0.157]	[0.126]
Hudson Yards	0.139	0.064	-0.177	-0.157	-0.139
	[0.107]	[0.112]	[0.193]	[0.189]	[0.132]

VARIABLES	(1) (1)	(2) (2)	(3) (3)	(4) (4)	(5) (5)
Madison/Fifth Avenue	0.255***	0.238***	0.276***	0.266***	0.246***
	[0.075]	[0.072]	[0.084]	[0.083]	[0.063]
Midtown Eastside	-0.253***	-0.200***	-0.175	-0.141	-0.200**
	[0.069]	[0.063]	[0.114]	[0.114]	[0.081]
Murray Hill	-0.408***	-0.449***	-0.460***	-0.419***	-0.424***
	[0.103]	[0.101]	[0.141]	[0.148]	[0.129]
NoHo Greenwich Village	-0.382***	-0.402***	-0.413***	-0.359***	-0.244**
	[0.106]	[0.092]	[0.135]	[0.137]	[0.119]
North Manhattan	-0.652***	-0.660***	-0.751***	-0.674***	-0.662***
	[0.067]	[0.069]	[0.134]	[0.131]	[0.164]
Penn Station	-0.600***	-0.579***	-0.579***	-0.515***	-0.305***
	[0.079]	[0.078]	[0.127]	[0.128]	[0.104]
Sixth Avenue	-0.153	-0.141	-0.082	-0.069	-0.157
	[0.106]	[0.107]	[0.122]	[0.123]	[0.121]
SoHo	-0.206***	-0.207***	-0.213*	-0.168	-0.043
	[0.075]	[0.072]	[0.123]	[0.123]	[0.098]
Times Square	-0.641***	-0.627***	-0.628**	-0.583**	-0.517**
	[0.227]	[0.238]	[0.260]	[0.263]	[0.257]
Times Square South	-0.374***	-0.359***	-0.465***	-0.413***	-0.266***
	[0.064]	[0.059]	[0.107]	[0.111]	[0.073]
Tribeca	-0.328**	-0.224*	-0.275*	-0.237	-0.079
	[0.131]	[0.136]	[0.164]	[0.170]	[0.148]
Upper Eastside	-0.252	-0.252	-0.266	-0.194	-0.185
	[0.276]	[0.282]	[0.298]	[0.300]	[0.229]
Upper Westside	-0.209	-0.233	-0.231	-0.187	-0.179
	[0.262]	[0.262]	[0.284]	[0.279]	[0.262]
World Trade Center	-0.202**	-0.262***	-0.631***	-0.628***	-0.589***
	[0.091]	[0.089]	[0.161]	[0.173]	[0.135]
Lease Commencement Date (Base case: Lease Commencement 2013)					
Lease Commencement 2014		0.096***	0.078**	0.095***	0.089***
		[0.033]	[0.031]	[0.033]	[0.034]
Lease Commencement 2015		0.177***	0.160***	0.174***	0.156***
		[0.035]	[0.033]	[0.033]	[0.036]
Lease Commencement 2016		0.249***	0.259***	0.282***	0.250***
		[0.038]	[0.039]	[0.038]	[0.039]
Lease Commencement 2017		0.296**	0.282**	0.335**	0.144
		[0.125]	[0.130]	[0.131]	[0.134]
Lease Commencement after 2017		0.399**	0.411***	0.413***	0.347***
		[0.163]	[0.136]	[0.139]	[0.087]
BUILDING QUALITY CHARACTERISTICS					
Building Age (Base Case: more than 90 years old)					
Less than 30 yrs old			-0.081	-0.067	0.034
			[0.176]	[0.169]	[0.148]
30 - 60 yrs old			0.204*	0.210*	0.278***
			[0.109]	[0.108]	[0.100]
60 - 90 yrs old			0.059	0.063	0.165**
			[0.076]	[0.075]	[0.066]
Building Renovation Year (Base Case: Renovation 2016)					
Renovated 2013			0.278*	0.289*	0.141
			[0.168]	[0.167]	[0.146]
Renovated 2014			0.104*	0.098	0.069
			[0.062]	[0.063]	[0.055]
Renovated 2015			0.251***	0.223***	0.222***
			[0.062]	[0.064]	[0.059]
Number of floors (Base Case: 31 to 45 floors)					

	(1)	(2)	(3)	(4)	(5)
VARIABLES	(1)	(2)	(3)	(4)	(5)
15 Floors or less			0.162**	0.165**	0.073
			[0.078]	[0.078]	[0.059]
16 - 30 Floors			0.025	0.036	-0.062
			[0.081]	[0.082]	[0.055]
46 - 70 Floors			-0.132	-0.136	-0.125
			[0.098]	[0.094]	[0.078]
More than 70 Floors			0.300	0.249	0.230*
			[0.185]	[0.179]	[0.135]
TENANT CHARACTERISTICS					
Tenant Industry (Base Case: Technology)					
Finance				0.054	0.049
				[0.052]	[0.046]
Government				-0.445***	-0.568***
				[0.170]	[0.162]
Healthcare				-0.041	-0.095*
				[0.059]	[0.052]
Media				-0.143***	-0.113**
				[0.053]	[0.051]
Non-Profit				-0.079	-0.044
				[0.115]	[0.135]
Other				-0.042	-0.033
				[0.062]	[0.059]
Retail				-0.098	-0.133**
				[0.062]	[0.062]
Service				-0.039	-0.032
				[0.044]	[0.041]
LEASE CONTRACT CHARACTERISTICS					
Transaction Type (Base Case: New Lease)					
Lease Expansion					0.016
					[0.036]
Lease Extension					-0.264**
					[0.106]
Lease Renewal					0.026
					[0.047]
Lease Renewal/Expansion					0.066
					[0.126]
Transaction Size (Base Case: Under 10,000sqf.)					
10,000sqf - 25,000sqf					-0.105***
					[0.036]
25,000sqf - 50,000sqf					-0.155**
					[0.069]
Over 50,000sqf					-0.089
					[0.063]
Lease term (Base Case: Less than 5 years)					
Lease term 6 - 10yrs					0.096**
					[0.040]
Lease term 11 - 15yrs					0.227***
					[0.057]
Lease term 16 - 20yrs					0.350***
					[0.072]
Lease term 21 - 25yrs					0.430***
					[0.104]
Free-rent period (Base Case: Less than 6 months)					
6 - 12 months free					0.074**
					[0.033]

VARIABLES	(1) (1)	(2) (2)	(3) (3)	(4) (4)	(5) (5)
13 - 18 months free					-0.002
					[0.047]
19 - 24 months free					0.081
					[0.089]
Broker Presence					
Landlord Broker					-0.005
(yes = 1)					[0.056]
Tenant Broker					-0.018
(yes = 1)					[0.041]
Sublease					
Sublease					-0.069
(yes = 1)					[0.058]
Constant	4.210***	4.069***	3.887***	3.910***	3.808***
	[0.054]	[0.054]	[0.120]	[0.118]	[0.093]
Observations	677	677	677	677	677
R-squared	0.335	0.384	0.438	0.462	0.540
F Adj R2	0.31	0.36	0.40	0.42	0.49

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

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