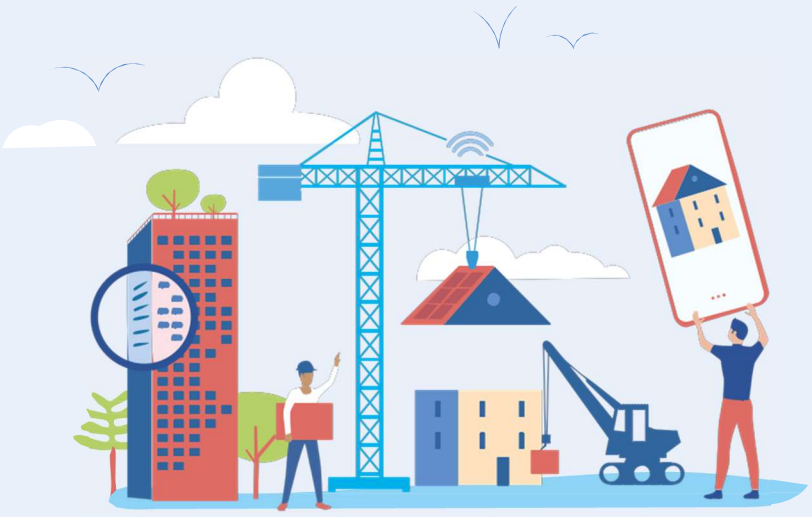
# Buildings of the future

## What challenges will they present for occupational safety and health?



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An INRS document produced by a working group coordinated by M. Malenfer.

May 2022

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# Introduction

In 2019, the French technical and scientific centre for buildings (Centre scientifique du bâtiment -CSTB) and the agency for the ecological transition (Agence de la transition écologique - Ademe) launched a prospective exercise aimed at helping building sector players to anticipate upcoming changes so that they can be better prepared for them. This approach, dubbed “Imagining together the buildings of tomorrow”, convened a working group of 17 people over the space of two years.

This exercise made it possible to provide a “prospective toolkit” to sector players, with a series of 22 sheets, in particular. These sheets address variables relating to the main drivers of change and make contrasting hypotheses as to the development of each of them, as well as four scenarios in an effort to project towards 2050 [1].

Called on by the leaders of the approach, the watch and foresight unit of INRS took part in this foresight committee in order to delve more specifically into the occupational safety and health challenges. To do so, an ad hoc group of experts on working conditions in the building and public works sector and on workplace design matters, coming from prevention organisations, academic fields and large companies in the sector[2] was created. This group worked all throughout the year 2021 and was supported by a consultant from the Futuribles foresight consultancy. It had access to the content produced by the first foresight committee and was able to use it specifically to produce scenarios and identify the occupational safety and health challenges which are presented in this document.

*1. All of the information about this approach as well as the elements produced within this framework are available at: https://www.batimentdemain.fr/*

*2. The following took part in this working group: Jacques Balzer (Carsat Alsace-Moselle), Marc Bury (Carsat Nord-Est), Alain Delage (VINCI), Jérémy Hauw (Bouygues Construction), Véronique Lamblin (Futuribles), Dominique Naert (École des Ponts ParisTech), Philippe Robart (OPPBTP), Jean-Christophe Visier (CSTB et Ademe), as well as Mathilde Silvan, Michel Héry and Marc Malenfer (INRS).*

# 1. Methodology

As mentioned in the intro, this exercise drew on an original methodology compared to previous prospective exercises led by INRS. Generally, exercises start off with a major phase defining and deciding on a series of variables deemed decisive for the future developments of the field in question. This material is then used to build scenarios and then deduce more specific occupational risk prevention challenges. In the present case, the ad hoc group obtained a considerable amount of information supplied beforehand by the working group steered by CSTB and Ademe in order to select and document 22 variables and formulate for each one, contrasting development hypotheses. However, among the topics selected by the initial working group, some have little to no influence on occupational safety and health matters. The group therefore selected seven variables that they considered most likely to have impacts on working conditions. It is on this basis that they then worked to build their own scenarios which were then used to identify a series of occupational risk prevention challenges.

The seven variables chosen by the group are:

- occupation of non-residential buildings;
- technical policy;
- obsolescence management;
- quality of use;
- organisation of the industry;
- materials and equipment;
- labour.

For each of these variables, a series of three to four development hypotheses were formulated. Logical associations between these hypotheses made it possible to formulate four development scenarios for the construction industry in the future. Summaries of the seven variables adopted and the hypotheses associated with each one, as well as the scenario construction table presented in this document are available in the Annex, page 43.

# 2. The scenarios

On the basis of the combinations of hypotheses presented in the table on page 55, the working group built four development scenarios for the construction industry in the upcoming years. The goal of these scenarios is to show a variety of possible futures regardless of whether or not they are desired. They are useful tools for facilitating reflection on occupational safety and health challenges. These four scenarios are:

- hard to do everything;
- sustainability companions;
- industrialisation and a circular economy;
- construction on digital platforms.

## Scenario 1: Hard to do everything

In this scenario, construction and real estate industry players are unable to switch from a supply strategy to a demand-response strategy. Real estate remains rather inflexible and struggles to adapt to the diverse demands made of it. Building quality is determined by supply, which is standardised to reduce costs. Project owners are limited by short-term challenges: compliance with regulations, cost control, work duration, etc., which make it hard to meet the expectations of increasingly demanding end users.

New build slows in a stagnating market and renovations do not take off for want of political proactivity. The integration of new requirements into the building stock is slow. The slow pace of renovations leads to a portion of this stock becoming obsolete.

Due to a lack of coordination and leadership, the industry does not solve its productivity issues. Its many players fight among themselves to obtain the largest share of profits without there being any improvements in quality and the overall value-added. Calls for tenders are designed so as to have all players compete: large and small, local and national (or European) in order to drive down prices.

New tools such as Building Information Modelling (BIM)[3] create competition among players and do not achieve their target objective of improved coordination: different computer solutions emerge, which are not always intercompatible. To revive activity, the majors push for the technification of construction processes (it would also solve the labour shortage), whereas public authorities promote frugality (lowering of VAT on local and bio-sourced materials, possibly being recycled) to reduce the sector's CO2 emissions. Some coordinators stay ahead by working on major innovative projects for large companies or public clients, but these projects remain a minority.

Recruitment difficulties increase in the sector. Companies cannot find workers with the necessary qualifications to meet their new challenges. The labour crisis in the construction industry makes it difficult to obtain the services of construction professionals, especially where individuals are concerned. Many households choose to do work on their homes by themselves: the do-it-yourself (DIY) trend takes off.

Against the economic crisis and strong competition, industry businesses use fall-back solutions which exacerbate matters: industrial relocations, "platformisation"[4] of trades, development of posted work, illegal work, etc. However, niche markets are not affected by this spiral.

*3. Building information modelling*
*4. The term "platformisation" here designates the use of digital platforms, a practice often called "uberisation".*

In this context, renovation concerns mostly interior design rather than structural work, and the DIY and equipment markets grow. Start-ups develop to assist individuals in this “ambiance” niche.

Relationships between landlords and tenants, or among owners within co-ownerships become tense because of isolated initiatives by residents, the lack of renovation coordination (regarding roofs, patios, heat protection, energy savings, etc.) and the lack of a framework for architectural choices.

In this scenario:

- BIM does not achieve its objective to improve coordination among players;
- Employment and working conditions are very different between a few large companies that manage to maintain margins on major projects and have the means to implement a coherent occupational risk prevention policy, and many small companies that endure the situation and attempt to seize opportunities in a very competitive environment.

## Scenario 2: Sustainability companions

Following the Covid-19 crisis of the years 2020-2022 and against the ecological transition, building takes on a key role in society. The huge leap in terms of energy renovation of buildings is the trigger in this scenario.

Environmental sensitivity and the belief that a large part of ecological reconstruction will occur through building renovation attract talent. The sector appears promising for players in crisis sectors who must reconvert. It in fact proposes a range of jobs, some rather demanding, but concrete, quite well-paid and distributed across the entire territory.

Awareness about the need to massively renovate a great number of buildings provides a breath of fresh air. Companies developing are those that adopt meaningful policies (benefit corporations). Conscious about the importance of sustainable development, they initiate an unprecedented wave of research and development to find sustainable construction materials and methods that promote reuse, recycling and bio-sourced products. Project owners become even more skilled which translates into a better consideration of long-term stakes in the project design phase.

Occasional project owners receive high-quality support from consular networks in particular (chambers of commerce and industry, chambers of agriculture, etc.).

The sector reorganises through better coordination of increasingly specialised professions in the service of global offers. Coordinators emerge among traditional players, drawing on the current ecosystem and its diversity, but also convey the need to be more effective quality-wise to be selected and connected with clients. This could take the form, for example, of trades cooperatives associating different professions and making it possible to respond to large calls for tenders. There are systems in place that promote small local structures and discard unreliable players (particularly in calls for tenders by local authorities). This leads the large companies in the sector to build networks of small local subcontractors in keeping with the principle of territorial proximity.

Paying attention to clients, the sector is able to propose customised renovations and high-performing new builds which adapt to the great variety of demands. Thus, offers develop combining comfort, quality of life (especially for ageing people), environmental performance, etc. Political proactivity enables the development of funding for these ambitious but costly renovation programmes.

In this scenario:

- Information systems are open and enable real coordination among actors without being prescriptive in the steering of their activity;
- The small companies in the sector have their say about the organisation of worksites;
- Coordination of players is essential.

## Scenario 3: Industrialisation and a circular economy

Building use changes greatly under the combined effects of the health crisis, the emergence of teleworking, the increase in time spent at home, climate change, etc. Existing buildings become obsolete more quickly; a large number of them are no longer consistent with the times.

Future occupants are stakeholders in new build projects and major renovations. Building and space flexibility becomes the focal point of new build.

Industrialisation grows, particularly in the new build market. The production of complex prefabricated components and offsite construction develop. Buildings are designed with the client based on these modules. The worksite becomes a place where industrial products are assembled. A large portion of value-added is transferred from the worksite to the factory. This industrialisation reduces building times and contingencies at worksites through precise logistics managed with digital tools.

Competitiveness of new builds in terms of quality, price, deadlines and environmental performance make them more appealing than renovations. A growing percentage of obsolete buildings becomes vacant (especially in low-demand areas [5]), is demolished (particularly in high-demand areas), or is used by those who seek low-cost property. New build market share increases; Haussmannian-style architecture dominates.

But raw materials for construction dwindle (sand, stone, etc.). The reuse of construction materials becomes a requirement (including with regards to regulations). The circular economy is used as much as possible and recyclable composite materials develop. Initially, it was difficult when suburban houses destroyed to be rebuilt had to be recycled, but techniques were honed progressively. Now, all products are planned to be dismounted and recycled. New build design is comparable to that adopted for photocopiers: with a large portion of components coming from recycling or being reused and a very technical and scalable functional layer. The quality of building use is handled by changing building components based on innovations and need developments.

In this context, project owners in the non-residential building sector adopt two types of stances. Some choose catalogue-based purchases according to basic functional and price criteria (this is especially the case with many SMEs) while others invest in skills and raise their requirement levels to reach high efficiency and circular economy performance (large companies and local authorities).

The reconstruction boom attracts labour. Labour is split between hazardous and low-value deconstruction tasks, and reconstruction, which is increasingly technical, mixing very qualified design jobs and assembly jobs in factories and at worksites, leading to the polarisation of the labour market in this sector.

In this scenario:

- Manufacturers capture a large portion of value-added and impose their products,
- Small companies are often reduced to deconstruction or assembly functions and hardly involved in design,
- Adeconstruction and reuse market emerges and recycling is industrialised.

*5. A large area is a territory where the supply of housing can meet the demand, as opposed to tight areas where there is a shortage of housing*

## Scenario 4: Construction on digital platforms

Taking advantage of construction and renovation players' lack of ability to adapt to the constantly evolving needs of users, new property service players emerge, first in niche markets, and then for the entire building stock.

These players are above all digital companies, experts in digital marketing, which become the main contact for occupants, guaranteeing them comfort and adaptation to their needs. Having major investment capacities, they run the building sector following an approach geared towards customer satisfaction and take under their control companies that perform construction, renovation and decoration work. Their economic model is based more on leasing or service subscriptions than on the selling of goods, both for individuals and professionals.

They rely on traditional players that deliver standardised building envelopes in the new build and renovation markets based on specifications defined by designers following mainly commercial criteria. The value-added for these products drops and intermediation is performed mostly by digital platforms that make tradespeople compete constantly. At the same time, they invest in innovative solutions to meet clients' expectations: self-cleaning materials (integrating nanomaterials), self-repairing materials (self-healing concrete), etc.

They also draw on very creative small companies that propose "furnishings and equipment", "moods" and "uses", and that know how to completely change the sensory feel of a space. They propose turnkey adaptations to occupants to better suit their needs: expansions, renovations, moving, etc.

The importance of customer satisfaction leads to increasingly customised services, and increasingly technical equipment, with home automation taking off. This contributes to a polarisation of the labour market, between those who design and steer (often remotely) and operators working at the locations whose activity is heavily directed through digital tools. Sometimes these workers can come from far, like the materials they use in a context of globalisation of construction value chains.

In this scenario:

- New digital players disrupt the sector by capturing clients;
- Incumbent players attempt to survive by imitating them;
- Small businesses and independent workers are forced to follow their lead and witness their jobs becoming impoverished in every sense of the word.

# 3. Occupational safety and health challenges in the structural changes to the construction industry

The scenarios presented in chapter 2 as well as the work done ahead within the framework of the “Imagining together the buildings of tomorrow” exercise highlighted drivers of change in the construction industry which will be decisive in the years to come. They break down into three fields: digitisation, environmental transition and industrialisation.

Depending on the scenario, the respective influence of these different factors will be more or less strong and may take on different forms, but, in any event, these factors will be the decisive drivers of change in the industry in the next few years and will each have an impact on occupational safety and health.

For each of these three fields, we focused on two transformations because of their possible consequences on working conditions.

## 3.1 Digitisation

The construction industry is also affected by the boom in the use of information and communication technology (ICT) which has an impact on all economic sectors. This digitisation of the industry is cross-cutting and is reflected especially in innovations likely to significantly transform work organisation for construction and renovation players.

The group selected two innovations which illustrate their impact on working conditions. It is a matter of, on the one hand, investigating the possible effects of the deployment of BIM, and on the other hand, of investigating the effects of the platformisation of a certain number of activities, particularly regarding finishing works.

### 3.1.1 BIM, a new tool in the service of prevention?

Business information modelling enables all of a project’s stakeholders to share information from the design phase to construction and then maintenance. It can assist, though not singlehandedly, with the coordination of players. That said, the availability of information shared among all stakeholders is a major element for strengthening prevention actions and therefore worksite safety. Many tools exist both for designing a digital twin for buildings and for sharing the progress of projects under construction.

BIM, like prevention, is based on principles, such as globality, interdisciplinarity and the involvement of all. This is why it offers new occupational risk prevention prospects for both new builds and renovation, but also for deconstruction operations and reuse, as well as for offsite operations.

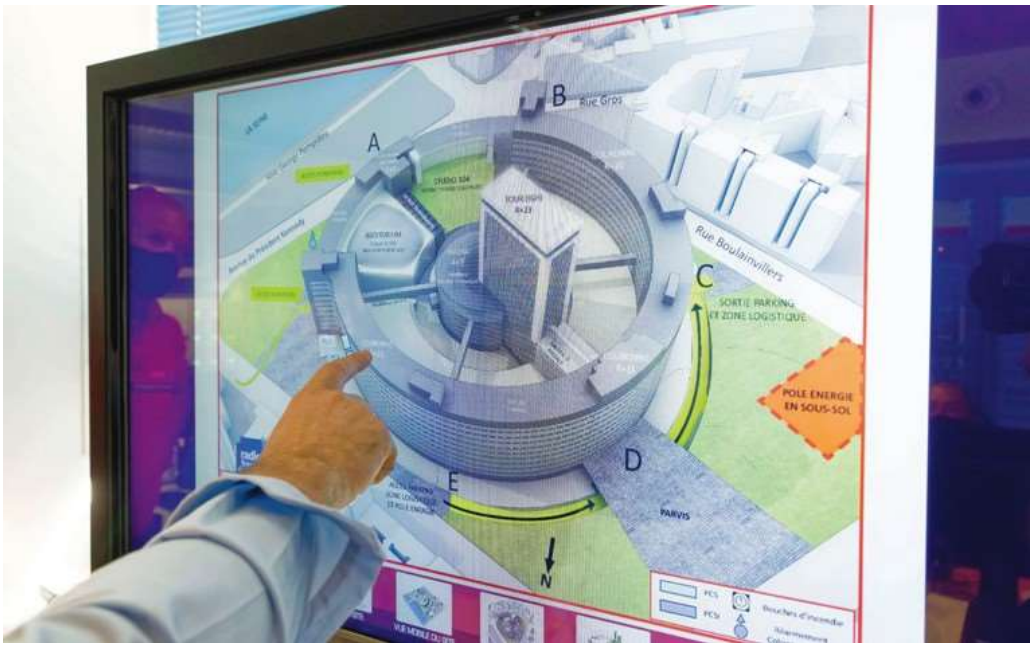
#### • What to expect from BIM in terms of prevention?

Many uses can be made of digital mock-ups to further prevention. For example:

- during preparation of the worksite, 3D visualisation, with the real dimensions, of all of the implementation challenges and risks that may arise when the project is being conducted. The BIM model allows the worksite to be built virtually integrating prevention before work actually starts;
- the possibility of modelling, in a sequenced fashion, the site layout plan, which can sometimes be dynamic, and flow management, which serves to anticipate as best as possible collision risks at a worksite;
- more specifically, the use of clash detection functions can inform decision-making in order to reduce risks. For example, these functions allow for verifying proper scheduling and therefore limits the number of drilling and sawing operations done subsequently. This has a direct impact on prevention, by reducing arduous work and exposure of employees and persons working nearby to dust;
- the combination of the definition of volumes where operations will be conducted and clash detection

functionalities. This makes it possible to verify, from design to reception, that surface areas where subsequent operations will be conducted are reserved for this purpose. As such, it can be checked that access conditions to maintenance zones are ensured throughout the entire work period, and that people intervening later on will be able to do so under the best possible postural conditions.

BIM, associated with 3D scanning software, is also effective for preparing renovation sites. Modelling existing structures can also involve retro-design [6]. When this is the case, information relating to asbestos and other compounds can be integrated into the mock-up. During the preparation of an operation, a request can be made on the BIM mock-up to determine the presence of these products and adapt the operating mode accordingly.

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*3D tactile screen showing the volumes of the Radio France building.*

Mock-ups of buildings to be destroyed are sometimes created, even though this seems counter-intuitive. For deconstruction and reuse, BIM can improve employees' working conditions. Modelling a building earmarked for deconstruction in fact requires, for each element modelled, knowing the type of material and updating the mock-up based on the associated diagnostics. This use of BIM reduces the share of contingencies at worksites, and therefore, employees' risk of exposure to hazardous materials such as asbestos. In addition, the functionalities of BIM make it possible to verify, at each deconstruction phase, the structural stability of the building, step by step. This has a direct impact on the risk of building collapse and on workers' safety.

BIM is associated with certain building trends such as offsite construction. This type of construction requires greater preparation because in situ adjustments to the building are more complex. BIM is a tool offering new possibilities to face certain situations, for example, by integrating data relating to the worksite environment (classification of roadways, presence of overhead or buried networks under concession, electricity, gas, telecoms, etc.) and therefore can play a part in risk analysis. Worksites incorporating offsite construction rely more heavily on lifting. Here again, BIM, through the integration of work equipment such as tower cranes, mobile cranes and telescopic forklift trucks, offers new prospects for carrying out suitability tests for lifting devices, and thereby preventing the risk of machine overturns.

*6. Reconstitution of a digital mock-up of an existing building.*

### • BIM and its limits

Like any tool, BIM has its limits. In this case, they are closely tied to the digitisation of our society. The first limit is digital illiteracy. A study by INSEE done on households concerning information and communication technologies, published in October 2019, shows that 15% of people 15 years and older did not use internet throughout the year. This study indicates that digital illiteracy concerns 17% of the population [7].

Digitisation and centralisation of information on platforms can also have the following consequences:

- disrupting, or even blocking access to information. Access to such information stored in clouds requires a minimum level of knowledge of digital tools, access points (computer, tablet, etc.), access rights and a network. All of these conditions can be obstacles at a worksite. Suspension of access can have negative consequences on the achievement of work and on workers' safety;
- modifying habits of viewing blueprints, even though building and construction workers are generally accustomed to 3D viewing;
- creating inter-generational conflicts or conflicts between those who master these tools and those who do not.

Another limit is that of the control of the BIM process. The digital mock-up and the resulting uses depend on the quality of information that is entered, and the command of tools related to the job:

- inputting data into the mock-up must be done following defined sequences so that everyone can draw on the data of others to complete their part of the work. Consultations, as for data input, can only be done by people trained in BIM software;
- the mock-up must be updated, particularly during discoveries after gutting, or when variants are decided in the course of a project. This mock-up must reflect the reality of the work, especially when the data is used within the framework of prevention.

Lastly, cyber risk is also a limit. Every year, cyber attacks are led against companies and their software editors, depriving them of access to the data stored on their servers. The scenario where a cyber attack is launched against hosting platforms, making mock-ups and health and safety data inaccessible, is possible.

Moreover, it is probable that BIM work will heavily mobilise players in the future, particularly as regards training. While there is no doubt that digital technology is promising, it can nevertheless become an autonomous object and can lead to the risk of disconnection from reality, with investment in digital buildings becoming a goal in itself, attracting capacity which will no longer be available for anything else. The quantities of data collected can, for example, be related to dreamed up or superfluous uses more than actual uses. Such a phenomenon was seen in quality-assurance controls which have sometimes become tools contributing to detaching "work on paper" from actual work, with the job disappearing behind the procedure.

*7. https://www.insee.fr/fr/statistiques/4241397*

## INNOVATIONS

- **Regarding the sharing of the digital mock-up**: the Lightyx platform transforms blueprints into interactive field tools in order to ensure that construction workers are able to correctly implement the 2D and 3D blueprints, and that managers are able to supervise the process; Wizzcad proposes mobile solutions for the operational follow-up of projects: digitisation of operational processes, document management and application of quality-safety-environment processes (QSE processes).
- **Regarding the construction of a digital mock-up within the framework of a renovation**: 3D scanning tools, such as those developed by My Digital Buildings, capture buildings' spatial information and thus enable the creation of a digital twin. Two tools are particularly interesting because they require only a smartphone: Magicplan, a solution for scanning a space rapidly with a smartphone, to create an interior layout and estimate the costs associated with renovation work, and Vyoo for scanning objects (all equipment) to reproduce it in 3D.
- **Regarding the consideration of the well-being of occupants as from the design phase**: Realiz3D is a tool for designing 3D digital mock-ups in real time which assures that it takes into account the well-being of users as from the digital design phase.

### 3.1.2 Platformisation

In the finishing work sector, connecting clients and companies is traditionally done directly or through the prime contractor (architect, etc.) if there is one. If there is not, then it is mostly through relationships (by word of mouth) or the use of online directories that it is achieved, which makes matching of peoples' needs with the competencies of professionals complex at times. Therefore, for a few years now, the sector has logically seen the emergence of platforms for business between individuals and professionals or "handymen" to do work in households. In a 2017 study, the French building federation (FFB) identified 150 such platforms in the sector. They most often propose services that go beyond their simple intermediary role. Some of them offer a guarantee in the event of damage and defects in partnership with insurance companies. They can also have connections or partnerships with do-it-yourself stores or distribution centres, building manufacturers and insurance companies.

#### ▪ Developments that can promote this platformisation

Over the last few years, we have seen many different types of changes that can favour the rise of this type of players.

**Regulatory changes**

The economic and regulatory context favourable to entrepreneurship causes undeclared work to lose its attractiveness, which leads to a share of activity being redirected towards companies and tradespeople.

**Social changes**

The development of Internet promotes the use of ecommerce and changes the behaviour of customers, who wish to be able, for all things, and therefore for finishing works also, to explore offers simply, from their home at any time, and obtain the corresponding services without delay. This behaviour grew during the Covid-19 crisis.

In addition, clients use service providers for finishing work less frequently than they use nearby convenience stores, and for much higher amounts. Therefore, they are less inclined to make mistakes and become increasingly cautious and demanding. The turnover of tradespeople and the anonymity of large cities are no longer favourable to word of mouth, which, for a long time, was the main way to find a high-quality tradespeople. In this context, the mediation between individuals and professionals provided by platforms reassures the client, especially through the reviews left by previous clients at the end of their projects.

Lastly, clients appreciate having access simply to the services associated with the project (insurance, maintenance, etc.) that tradespeople alone, in their traditional organisation, cannot always propose to them.

**Technological changes**
The progress of web applications makes ecommerce more and more pleasant, and it develops greatly.

With the processing of clients' and professionals' data, platforms improve the matching of supply and demand and reduce wait times.

**Organisational changes**
Faced with the change in clients' behaviour, tradespeople increasingly require support. To better attract and retain tradespeople, platforms can offer them more and more services (management of their commercial approach and administrative tasks, etc.) to enable them to concentrate on their core business.

The major building and public works players are sensitive to the flexible platform model which responds to the expectations of individuals. By taking over platforms or forming partnerships with them, these major players expand their activities by proposing a complete service, which enables them to control the sector and retain their clientele.

## ▪ Consequences in terms of working conditions

In the organisational development of this sector, certain elements can bring improvements to working conditions.

Intermediation of the platform can allow for the regulation of the market by avoiding low-cost services which promote occupational accidents.

To attract and retain tradespeople, platforms can invest in risk prevention. Thanks to their data processing capacity, they can advise tradespeople, guide them in their operations and anticipate the risks at each worksite. By federating numerous professionals, they can help them gain easier access to safety equipment, either by sharing them (e.g. safe scaffolding), or by negotiating prices with suppliers (e.g. for PPE). Occupational safety and health then becomes a marketing argument for platforms, with regard to clients and professionals. Working conditions improve compared to the previous market that was essentially composed of very small enterprises that had neither the means nor the time to invest in prevention. Platforms can relay prevention messages to tradespeople. Professionals, relieved of administrative and commercial tasks thanks to the platforms, can devote more time to their job and the improvement of their working conditions.

Certain elements can however contribute to deteriorating working conditions.

Tradespeople's dependence on the platform reduces their freedom to organise their work, without the platform bearing in return the responsibility concerning prevention. Being forced to use a platform can heighten tradespeople's isolation, as they no longer have contact with their suppliers, and interaction with clients is reduced to a minimum. An algorithmic approach to work also deprives them of the possibility to discuss their work organisation to adapt it to their constraints, since exchanges with the platform are limited by digital interfaces and sometimes processed by chatbots.

Tradespeople's economic dependence on the platform exposes them to unilateral decisions made by the platform: modification of tariff rules, delisting because of bad reviews from clients, etc.

The distance from the field (project, then worksite) can also lead to using non-professionals (or occasional professionals) whose actual competencies are not known, particularly in terms of preservation of health at

work, for them and for other participants (during co-activities and in the absence of formal or organised coordination for safety and health protection.

Similarly, remote work on the (future) site can lead to assessment errors, because of information taken too narrowly. For example, too small a worksite can hinder the use of a suitable crane for the lifting operation planned (see the example of Clever Lift in the box on the following page).

## INNOVATIONS IN THE B TO B PLATFORMISATION OF THE SECTOR

- **Platform for the purchase of materials and equipment, particularly for SMEs without a structured procurement department**. These platforms propose two tools: marketplaces that provide all supplier worksite products and tools for managing invoicing and expenses. In terms of occupational safety and health, these platforms could propose better documentation and methods for using products and materials.

  Examples: the Ibat platform simplifies expenses at worksites in three fields (procurement, subcontracting and labour); Beton direct is a national platform of concrete plants. Regarding material, Traktor.fr proposes construction machines for rent online, with a simultaneous comparison of several rental companies; Clever Lift developed an application to find the right crane based on measurements performed at the worksite; and the Sharemat application develops two platforms: Sharemat Fleet to digitise and optimise the management of one's material stock, and Sharemat Community to share its use.

- **Platforms for connecting with subcontractors, which enable companies to find subcontractors more easily and obtain information about them**. They allow SMEs and tradespeople to have greater visibility to access projects, or reduce the administrative tasks for these small players. It would be useful for these platforms to take up risk prevention and safety rules; for example prevention criteria could be integrated into the assessment factors for subcontractors. Examples: Subclic, a collaborative platform for managing all subcontracting documents; Mylkee, a data purchasing and analysis platform which optimises the consultation of subcontractors and the estimation of projects; Batiref, a collaborative platform for the evaluation of building professionals based on feedback by clients and a supplier assessment system.

## 3.2 Environmental transition

The building sector is particularly concerned by the changes involved with the environmental transition. The objectives placed on it (or that will be placed on it) are numerous: reduce CO2 emissions from construction processes, lower the energy consumption of existing and future buildings, limit land alteration, adapt buildings to climate hazards which occur more frequently, find solutions to supply scarcity concerning certain materials, reduce the volume of final waste generated, etc.

Among all of these challenges, two are developed here to highlight the major implications of future changes to the organisation of the sector and working conditions. These are buildings' energy renovation policies and the development of a circular economy for the sector.

### 3.2.1 The challenges of energy renovation policies

Several policies aim to renovate the building stock (here, it is mostly a matter of renovating housing):

- energy-related retrofitting, whose goal is to lower energy consumption and/or carbon emissions;
- social retrofitting, whose goal is to combat energy precariousness (the "Live better" programme by the national housing agency, Anah), to adapt the home to the residents (programmes by the national pension fund - CNAV, for adaptation to ageing, etc.);

- urban renovation, whose goal is to contribute, through the quality of the building stock, to the living standard of neighbourhoods (programmes by the national agency for urban renovation - ANRU, city centre improvement programmes, etc.);
- possibly in the future, renovation for climate change adaptation (installation of air conditioners, consolidation of structures because of clay migration/swelling).

Tradespeople and companies play a role in all of these policies, which are managed in silos, and their integration is a major challenge, because they all have the same physical purpose (the building stock) but not necessarily the same methods of operation.

There are three types of challenges related to these policies:
- increase the number of renovations;
- increase the quality of each renovation, this is the case, for example, for energy, with the will to increase the number of efficient retrofittings;
- link up these different policies.

They can have significant impacts on safety conditions at worksites. In most cases, consequences on working conditions can be both positive and negative. How can renovation policies influence working conditions? Several hypotheses can be formulated.

Concerning renovation of social housing, the major uncertainty is that of the volume of funding: social housing providers are enthusiastic about renovation, they have inhouse project management skills. Only the funding mode for the social housing, and its impact on their capacity to fund work, can break the dynamic. Therefore, there is little impact on working conditions. As a result, attention must be focused on private housing.

Concerning renovation of private housing:

- **according to the type of renovation** (i.e. to what capacity can the renovation policy massively develop a global/integrated renovation market?):
- **either a step-by-step operation**: one year, the boiler is changed, another year, part of the home is insulated, another year, the bathtub is replaced by a shower to adapt the home to the ageing of occupants, etc. This is a trend. It hardly changes working modes because each profession operates independently, in direct connection with the project owner (individual owner occupant or landlord). This way of working follows the pace of households, but does not meet objectives (the step-by-step mode, even it covers all work items, will allow sufficient lowering of energy consumption as to reach France's climate goals only if energy decarbonisation is substantial);

*An exterior insulation project for a high-rise building.*

- **or a more global renovation**: this is a substantial energy renovation to reach low consumption in one go or in stages. It covers energy aspects and other dimensions (adaptation to ageing, to climate change, acoustics, etc.).

This would be a major change compared to the historic trend, but some minor signals are currently visible (for example, global renovation has begun to be promoted in MaPrimeRenov[8] (government subsidies for energy renovation). It will greatly change ways of working, since it will require coordination among different professions. In this case, the question becomes: who will be charged with coordinating work, i.e. with assisting the project owner? A group of tradespeople (Dorémi model[9])? A general construction company? Intermediaries such as with the energy savings certificates mechanism? Platforms such as Izi by EDF, La Maison Saint-Gobain, etc.? New build players in the process of transitioning? The development of a "renovation chaperone" is currently being discussed. Depending on the supervisor, tradespeople's working conditions can be very different, in their connection with the end customer, in their relationship of subordination with other players, in their capacity to choose their projects, to issue a technical recommendation (and therefore to control the equipment and materials to be used) and to share tasks at the worksite, but also in their need to invest time in the administrative and financial management of their company, etc. Each configuration has its advantages and disadvantages in terms of working conditions;

- **based on the quantity and quality of labour available** (i.e. to what capacity can the renovation policy attract the labour necessary in the sector?)**.**

Tradespeople and companies participate in these energy renovation operations, which all have the same physical objective (the building stock), but not necessarily the same methods of operation. Several development hypotheses concerning the impacts (positive and negative) can be formulated concerning working conditions regarding four key factors related to energy renovation.

### ▪ Labour and skills

The achievement of renovation goals requires a major increase in available labour in the construction sector, but also a strong need for training, for example to acquire cross-cutting competencies. Three types of competencies are necessary: technical, organisational and relational.

Within this framework, three development hypotheses can be considered.

**Hypothesis 1:** inability to draw quality labour or in sufficient quantity makes it impossible to reach objectives. This hypothesis can be viewed as a trend. It would lead to overload for tradespeople and tension with clients at worksites, but also an increase in their capacity to "choose" their clients, and to the development of new professions that are meaningful in supporting autorenovation, with individuals using their available time to make up for the absence of labour in the sector.

**Hypothesis 2**: the building sector manages to attract new labour by showing that it is an up-and-coming sector which offers concrete jobs, which are meaningful and rather well-paid. It becomes attractive for workers changing careers and for new people entering the labour market. It especially takes advantage of the loss of attractiveness of other sectors and invests in the training of this new labour force particularly regarding safety topics.

With regard to working conditions, one of the consequences is a change in pride and the meaning of work, but also longer time spent in training than currently, in order to update competencies based on technical developments.

**Hypothesis 3**: the building sector has a large number of low-skilled workers and hardly invests in their training. By attracting low-skilled labour and not having the capacity to invest in training, the building sector is faced with a decline in quality. In terms of working conditions, this could lead to an increase in the number of accidents, a rise in psychosocial risks and the establishment of a climate of mistrust between clients and tradespeople.

*8. https://www.maprimerenov.gouv.fr*
*9. https://www.renovation-doremi.com*

## ▪ Balance between quality and quantity of work

The desire to massify energy renovation can bring a new balance between the quality of renovations and their quantity.

The possible hypotheses are as follows:

**Hypothesis 1**: quality brings quantity. Players learn to propose well-coordinated quality renovations by drawing on the necessary complementary competencies. Client satisfaction brings a progressive but strong development of the market.

**Hypothesis 2**: the obligation to perform the work pushes quality downwards. Renovation obligations lead a portion of players to fulfil requirements without concern for the quality of the work. What matters most is to work fast rather than to work well. Project owners aim only to obtain the energy performance diagnostics authorising them to lease the property and they put pressure on companies without worrying about the quality and effectiveness of the renovations.

## ▪ Impact of funding subsidies

Multiple subsidy systems aimed at facilitating thermal renovations are set up. Three hypotheses can be made about the impact of these subsidies.

**Hypothesis 1**: subsidies enable project owners to conduct work that they could not have performed otherwise and the market grows. In terms of safety and working conditions, the question re-arises about the quantity of skilled labour that is necessary.

**Hypothesis 2**: subsidies lead companies to raise their prices and margins. This could result in less tension concerning working conditions, with market conditions allowing for prevention to be taken into account.

**Hypothesis 3:** subsidies lead to the creation of “bounty hunter” companies which appear, disappear or re-organise based on the development of subsidy systems. The term “écodélinquant” was invented for some of these companies that practise social dumping, use illegal work and where working conditions are precarious.

## ▪ Performance obligation

In order to guarantee the quality of work, methods arise to measure the performance of the work completed. Measuring a building’s air permeability has developed since the low-consumption building label in 2007 and the thermal regulation RT2012. The environmental regulation RE2020 and the associated label will lead to a verification of the functioning of ventilation and probably, in the long term, of the quality of the implementation of insulation. The air permeability measurement rather had the effect of encouraging the training of operators.

In terms of working conditions, two hypotheses can be formulated:

**Hypothesis 1**: the measurement of performance associated with training leads to acknowledging work well done and giving meaning to professions. In addition, for companies it reinforces the value of protecting the health of their experienced and trained employees to retain them and keep them working.

**Hypothesis 2**: performance measurement places a performance obligation on workers which can be a burden. An individualised assessment of the results of work can be a source of psychosocial risks for operators especially if they do not have the means (time, equipment) and autonomy (qualifications) enabling them to perform high-quality work.

## INNOVATIONS IN TERMS OF STEERING AND MONITORING OF BUILDINGS' ENERGY PERFORMANCE

- Sensors associated with processing platforms enable the intelligent control of buildings' energy performance. For example: Qualisteo proposes a system for measuring energy consumption through intelligent sensors and enables multi-fluid mapping by zone, device and use; Hxperience provides a solution that collects, processes and analyses in real time the data coming from buildings, equipment and use in order to improve energy performance and perform predictive maintenance.
- Another innovation uses basement temperature to improve the building's thermal capacity: Celsius Energy connects new or existing buildings to their basement's energy. They supply "low-carbon" heat and air conditioning or natural cooling.
- Apart from design firms specialised in energy renovation, an application such as CapRenov+ can be used to perform renovation work simulations.

### 3.2.2 Circular economy

In a context where raw material resources could become scarce in the upcoming decades and where climate constraints require lowering energy consumption (especially fossil energy), the switch to a circular economy is considered as one of the preferred solutions. The components of the circular economy transcend the reuse of elements and the recycling of materials, since it also includes, for example, the shared use of goods, industrial and territorial ecology, collaborative consumption, etc. However, as part of this prospective exercise devoted to construction, it is the first two elements (reuse and recycling) that will have the greatest impact on occupational health matters.

*Projection of a coating comprising a mix of hemp fibres, dry earth and a slip (semi-dry process) to design an insulating panel.*

#### ▪ Designing differently to enable reuse

In order for dismantling operations to be performed correctly, it is necessary to design differently. Design must take into account, in particular, the increase in workers' manual interventions which results from the greater number of dismantling operations preserving the integrity of objects. It must limit accidents, but also lower back pain and musculoskeletal disorders of the upper limbs, whether they are caused by the weight of components, forced movements, poor work postures or repetitive movements or movements causing strain on joints.

This improvement in design should pay off over time: all reusable elements will have had to be designed taking into account the logic of reuse, which generally has not been the case until these last few years.

In some cases, it is not a matter of an identical reuse of the deconstructed product, but rather a selective reuse (or repair) of one of its components: the dismantling of this particular element must also have been planned as from the design phase. It must also be ensured that workers have been trained in these specific tasks in order to avoid all accidents.

### ▪ Ensuring traceability of elements reused and materials recycled

The reuse of construction elements must meet certain traceability criteria in order to guarantee their harmlessness, for consumers but also for workers. During both their dismantling and re-assembly, these elements may be subject to constraints creating risks of breaking, which can evidently represent a risk for workers. Each element must therefore be associated with a lifetime and/or a limited number of uses which can be discovered via a permanent marking, giving access to a record of its use.

Similarly, it must be ensured that recycling of materials guarantees sufficient technical quality, but also that it does not result in the generation of pollution by toxic compounds or a gradual build-up of impurities which themselves are toxic. In this case as well, good traceability of series used must be guaranteed.

Lastly, the chemical risk generated during the use of new materials and recycling of old materials must be given specific and continuous attention (see section 4.3 page 30).

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- StockPro, a platform that can be considered as specialising in the circular economy, proposes a tool for managing companies' stocks enabling the reuse of dormant construction materials.
- Other companies propose waste collection and reuse solutions, from the reservation of dump trucks in one click (MyBen) to an intermediary that connects tradespeople with professional waste collection centres by negotiating tariffs and facilitating payment (Ecodrop), and even installation of waste sorting stations at worksites so that companies can sort their waste (Tri'n'Collect). This last start-up collects the waste and sorts it before sending it to recycling and reuse branches.
- Companies propose to further integrate recycled materials into their construction materials. For example, Néolithe transforms non-recyclable waste into ecological construction material; Etnisi proposes decorative and construction materials made 75% from waste; Materr'UP produces structural and cooling concrete from a patented clay cement ("green" concrete made of clay extracted from quarries and of soil excavated at worksites); Carbon8 developed a waste carbonation process for the production of raw materials for construction; other companies recycle fabric or plastic to incorporate them into construction materials.
- Platforms and tools are devoted to reuse. Backacia is a marketplace for the reuse of worksite materials, whether they come from deconstruction or surplus stocks; similarly, Cycle-up optimises the match between supply and demand for reuse materials, with practical sheets and concepts on how to use them. The collaborative platform Upcyclea qualifies data on buildings' assets and materials in order to promote the progressive elimination of waste and the reuse of resources. To improve occupational risk prevention, the qualification of materials to be recycled is essential.

## 3.3 Industrialisation of the sector

The combination of the new opportunities afforded by technological progress and the constraints faced by the building sector – here we think in particular of recruitment difficulties and quality issues – encourage professionals to develop new solutions to improve their productivity. These innovations are not only technical, they often imply major organisational modifications. Through different aspects, construction processes draw closer to industry processes. This matter of industrialisation is addressed here through two phenomena: that of the development of offsite construction and that of the emergence of robotisation at worksites.

*Welding operation on a metallic structure with a blowtorch*

### 3.3.1 Development of offsite construction

Construction modes and methods continue to change constantly and tend towards greater industrialisation of processes through offsite construction, with prefabrication or modular building. This trend can be interpreted from two point of views which are not incompatible. On the one hand, this process can be considered as an adaptation by companies to the difficulties in recruiting labourers to work at construction sites. On the other hand, these organisational innovations change the sector's labour needs. What is clear, is that these techniques will most likely improve the working conditions of operators in the sector, for several reasons:

- working conditions in workshops are much easier to control and improve than at construction sites;
- in a workshop, it is possible to invest in stationary equipment (machines, handling equipment, etc.) which can improve safety and reduce physical load as well as make workstations ergonomic, which facilitates employment of women and seniors;
- the ability to propose a fixed workplace to a portion of workers can be a major argument for recruiting them and retaining them (work-life balance);
- the consequences on working conditions at construction sites can also be positive since prefabrication requires greater mechanisation of handling because of the size and weight of the elements to be assembled. Even the duration of work at the construction site can be shorter;
- these production modes also limit time constraints, as certain operations can be anticipated ahead of construction.

A study done by the Kyu Lab firm for the Occupations and qualifications observatory for the building sector is devoted to these prefabrication and industrialisation issues[10]. It clearly highlights the improvement of workers' working conditions as the first advantage cited by professionals. Professionals also cite the disadvantages they associate with these techniques, such as a risk of deskilling of the labour force and a reduction in the freedom and autonomy of workers at construction sites.

The study also pinpoints the impacts of the development of these construction modes on professions and competencies. In terms of key skills, it highlights in particular, computer-aided design (CAD), the logistics and coordination of the construction site which become decisive; further downstream, lifting and handling needs as well as the technical competencies for implementation and installation. For these new projects, key workers will be designers, logistics specialists, but also crane operators (which is already somewhat the case at numerous traditional construction sites).

*10. https://www.metiers-btp.fr/publication/les-impacts-de-la-prefabrication-industrialisation-sur-lorganisation-des-entre- prises-et-metiers-du-btp/*

For certain functions, particularly in workshops, it will be easier to integrate operators that have followed non-specific building and public work training. At construction sites, the skills needed are mainly related to installation phases. It can be imagined that in the future, manufacturers will play an even greater role with regard to the training of labourers and tradespeople on how to install their equipment.

In many cases, working in factories or workshops therefore enables better prevention than at construction sites. It is easier for these places to have dust collection mechanisms, machines for heavy lifting, sanitary facilities, heating systems, etc. However, since they can also optimise processes a lot easier, this could lead to work intensification and an increase in pathologies such as musculoskeletal disorders.

*Installation of a roof truss on a multi-residential building, assembled on the ground, then mounted with a remote-control crane.*

But, this is not a turn that is easy to take. While in the wood sector of construction, many hazardous tasks can be automated, with systems that are quite flexible, this is not as easy in the concrete sector. In addition, prefabricated concrete elements are very heavy and are rarely self-supporting; their handling therefore requires suitable machines, access roads that can bear this heavy weight (this can be complicated in urban areas for example, because of the instability of certain roads). The prefabrication of more voluminous (and therefore heavier) elements, which must be placed in a smaller environment (densification of spaces) can create installation constraints and therefore additional risks. Moreover, with such elements, contingencies and “the last metre” are more complicated to manage and improvisation can be dangerous. Professional training of crane operators will be a major factor for risk control.

In addition, prefabricated elements raise the question about quality because they are harder to correct in the event of defects, which can pose a risk both to the construction operators and to the economic viability of the project itself.

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- Examples: Corner develops innovative prefabricated wood modules enabling mass production offsite, easy transport and assembly of the prefabricated panels (walls, floors) on site; Smart Cast proposes printed formwork panels delivered tailor-made for construction sites; Rebartek supplies prefabricated reinforcement cages for construction projects, and Revolubat makes prefabricated systems to simplify the incorporation of plumbing networks at worksites.
- Modular and scalable construction solutions, for example: Vestack designs and builds biosourced modular buildings (buildings with wooden structures, 90% pre-assembled offsite); Cubik Home has developed a construction offer with concrete to make an insulated envelope taking the form of modules that can be assembled; Agilcare makes ecological buildings using prefabricated, long-lasting, wood elements with standardised dimensions, which can be disassembled, re-assembled, and are scalable and transformable.

### 3.3.2 Technological innovations at worksites

Apart from offsite production, can construction jobs be automated? Can people be replaced by robots at construction sites? In an attempt to answer these questions, the working group chose to list here a certain number of innovation examples that show the profusion of projects in this field, irrespective of their viability. It cannot be denied that there are numerous projects under research and development in this field and they are often driven by productivity goals: gain time, reduce the number of workers at worksites and improve quality. Some aim more specifically to improve working conditions or protect operators. Not all of them will be successful because this depends on many economic, technical and human factors; some will redirect their attention on niche markets, but others could spread and contribute significantly to changing construction methods and working conditions.

***Of note**: Many brands and companies are cited in this section (as in other parts of this document). The descriptive elements of the solutions they propose are partly extracted from their promotional material. But here, it is not a matter of promoting them, and even less of endorsing their interest in prevention. The goal is to highlight the reality and the diversity of innovations in progress and to enable readers to access more precise information if they so desire.*

#### ▪ The robot-tradesperson (bricklayer, tiler, painter)

Hadrian X is a robot-bricklayer[11] developed by an Australian company (FBR) in 2015-2016. It lays bricks (12 times bigger than standard bricks to optimise laying speed) and mortar without the help of a human. In 2018, it constructed a 180 m2 house at a test facility in three days. In 2019, construction tests were done outdoors to validate its use under real conditions (wind, heat, etc.). The robot can lay 1,000 bricks per hour whereas a bricklayer can lay 400 per day. This type of robot aims to completely replace bricklayers.

Sam 100 is a semi-automated robot, developed by the New York company Construction Robotic, and has been on the market since 2015. It aims to assist bricklayers and not replace them completely. It uses conventional bricks but multiplies the bricklayer's productivity by 3-5 times (2,000 to 3,000 bricks per day instead of 500 for a traditional bricklayer) and is sold for $500,000 US. The robot picks up the bricks, applies the mortar and positions the bricks on the wall, but requires a worker to smooth out the mortar along the wall before the robot places another brick. The benefits put forward by the designers are, apart from productivity, a 50% reduction in labour costs (the robot replaces one out of two bricklayers), an 80% drop in load lifting and a decrease in occupational risks. This semi-automated bricklayer has already been used by several American construction companies[12] (sometimes on lease for $20,000 US/month). It was used, in particular, to build the Jay and Susie Gogue Performing Arts Center in Auburn (Alabama, USA).

*Bricklayers using a manipulator arm to move bricks*

*11. https://www.futura-sciences.com/maison/actualites/ce-robot-peut-construire-votre-maison-3-jours-73917/ and https://redshift.autodesk.fr/robot-macon/*
*12. The semi-automated Mason 100, Andrew J. Madsen, California Polytechnic State University, San Luis Obispo, 2019. DigitalCommons.Calpoly.Edu*

For this project, the number of bricklayers was cut by three (4-5 instead of 15-20), with two workers mixing the cement, two cutting the bricks and putting them in the robot and one worker controlling the robot. Its advantage is twofold: productivity and quality. The laser-guided system for laying bricks is much more precise compared to what a human can do. However, if the work does not start on ground level, in the case of a floor to be built over an existing construction, it can take more than a week to correctly install and adjust the robot. Given the space needed, the robot is more suited for new builds rather than renovations in a limited space. The same American company also sells a lifting robot for construction (Material Unit Lift Enhancer - MULE), which moves and positions heavy material at construction sites.

The robot tile layer and the automated tile-laying machine also exists (Si2y company). It won the 2016 Lépine prize (see photo 1). Its inventor has already placed it on the market[13] (adapted for large surfaces evidently), but few examples of completed projects are available.

© M. Zaatouti (2022)

*The robot tile layer from the Si2y company.*

Painting robots have been used for decades in the automotive industry. Regarding the building sector, many solutions are being researched and developed: from articulated arms to climbing and painting robots for surfaces at heights, drones, etc. The difficulty in this sector is that it is necessary to scan the surface to be painted in order to programme the robot (BIM innovation will therefore facilitate this task). Supplying drones with paint is also a challenge. Paco[14], the little painting and sanding robot on wheels equipped with an articulated arm (see photo 2), developed by the Les compagnons start-up with the Ecole des Mines de Douai, in partnership with Akzo Nobel, was still in the prototype stage in 2020. The idea is to target renovation operations by scanning the surfaces to be painted.

© Antoine Bernuit (2022)

*Paco, the paint and sanding robot on wheels.*

13. *http://www.si2y.com/realisations/machine-auto- matique-a-carreler/*
14. *https://zepros.fr/paco-le-petit-robot-qui-va-don- ner-un-coup-de-main-aux-peintres--85718*

The Les compagnons company also produces robots for assisting with painting in the building sector. The Paintup company developed an autonomous robot solution for cleaning, stripping, painting and drilling the facades of buildings up to 10 storeys high (see photo 3).

Lastly, more general-service robots are proposed by Robot at work which has created a modular robot platform that can be used for automating repetitive and fastidious work processes. Toggle sells an articulated arm that assembles metallic reinforced cages in concrete structures.

© Romaric Gonnet (2022)

*A painting robot for buildings developed by the Paintup company.*

## Deconstruction robots

Husqvarna and Brokk sell a series of remote-controlled deconstruction robots. These robots are used to keep operators away from the risk of collapse and projections. In this field, a Swedish company, Aquajet[15], sells precise hydro-demolition machines that avoid micro-cracks and dust and “demolishes only the degraded part of large concrete constructions (bridges)”.

## Exoskeletons

The German company Ottobock[16] produces and sells Paexo, light exoskeletons (less than 2 kg) to facilitate work at heights (arms raised) at construction sites. It is intended for drywall workers, plasterers and painters. The weight is transferred from the raised arms to the hips using a mechanical cable pull technique. This exoskeleton is already used at assembly lines in the automotive industry (Volkswagen). The same company also sells “Paexo back” to reduce back strain, and is intended rather for logistics operators who carry loads repeatedly. It could also be applied in building. Although relatively expensive, the cost of exoskeletons will remain much lower than that of automated machines.

© Patrick Delahaye pour l'INRS

*The development of a tailor-made exoskeleton enabled the Paris company Stuc & Staff to limit the risk of MSDs at its renovation worksites for a specific task – sanding of ceilings.*

Many other companies develop various other exoskeletons to reduce musculoskeletal disorders and improve workers’ productivity (HTM, Moten, Bioservo, RB3D, COBO4YOU, etc.). The first active exoskeletons are appearing on the market. Other companies are developing more specific solutions, such as Vizo, which has created a headrest for people working long periods with their heads tilted upwards. Percko sells posture correctors and posture sensors and Nuada proposes a support glove which enables operators to hold up to 40 kg of load with no difficulty.

15. https://www.aquajet.se/hydrodemolition/
16. https://paexo.com/?lang=fr

## ▪ Smart objects or the Internet of Things (IOT) [17]

Sensors and smart objects (interconnected sensors linked to a monitoring and management platform) have the advantage of being much less expensive than all the other innovations we have classed here among industrialisation innovations for construction sites. Large companies that have a considerable stock of material heavily develop these solutions to limit losses, theft and damage, to reduce maintenance costs and the risk of material failure and especially to optimise logistics and the use of equipment.

Because these tools make it possible to have the right material at the right place at the right time, they can have a positive impact on safety at construction sites.

For example, HeronTrack proposes a solution to remotely manage the internal and external material of construction sites, through the implementation of a tracker and an application. Omniscient is a platform that processes geolocation data and supplies performance and measurement indicators for operations such as material stock management, production methods, site safety and goods logistics. The construction material supplier De Walt is launching its new version of the Tool Connect solution which enables professionals working at a construction site to manage their equipment options via their smartphone and make the location of the material accessible to all; lastly, CAD.42 which developed a smart vest that pinpoints in real time the location of the person wearing it.

A specific case is that of smart glasses. Ellcie Healthy, for example, develops smart, connected glasses with evolving functions (accelerometer, eye sensors, etc.). Connected glasses can also enable operators to receive instructions remotely, and access information while working.

## ▪ 3D concrete printing

3D concrete printing for construction promises time saving in manufacturing, waste reduction, optimisation of the materials used (since it is a matter of additive manufacturing line by line), more freedom in shapes and the decrease in arduousness and accidents.

In France[18], the first house built with 3D printing (the envelope only) was completed in Nantes in 2017 by Bouygues Construction in cooperation with research teams from Nantes university. A 95 m2 house took form within three days through the articulated arm of a robot. Two polyurethane wall panels were printed into which concrete was poured.

Late 2020, the first 3D printed house was sold in Long Island, USA by SQ4D[19]. The 130 m2 house cost $300,000 US, i.e. 50% less than for the traditional construction of the same house (it is estimated that the cost of a 3D printed house is 30 to 55% lower than a traditional construction). Nevertheless, the printer used and developed by the ARCS company is enormous since it can print buildings from 46 m2 to 92,000 m2.

Today, there are over 13 manufacturers (including projects) of 3D printers for construction[20] in the world, two of which are in France. Often, they “print” concrete directly in the form of a molten semiliquid material from a nozzle. The printer creates foundations, walls and the roof of the construction. The cost of a wall printed in 3D would be $27 US with the 3D Apis Cor printer compared to $75 US with traditional methods, in addition to the significant time savings. Other examples can be cited (see Figure no. 1, page 27).

*17. Internet of Things*

*18. https://www.bouygues-construction.com/innovation/toutes-nos-innovations/limpression-3d-pour-construire-une-maison*

*19. https://www.3dnatives.com/en/sq4d-puts-first-ever-3d-printed-010220215/*

*20. https://www.aniwaa.fr/guide-achat/imprimantes-3d/imprimante-3d-construction-maison/*

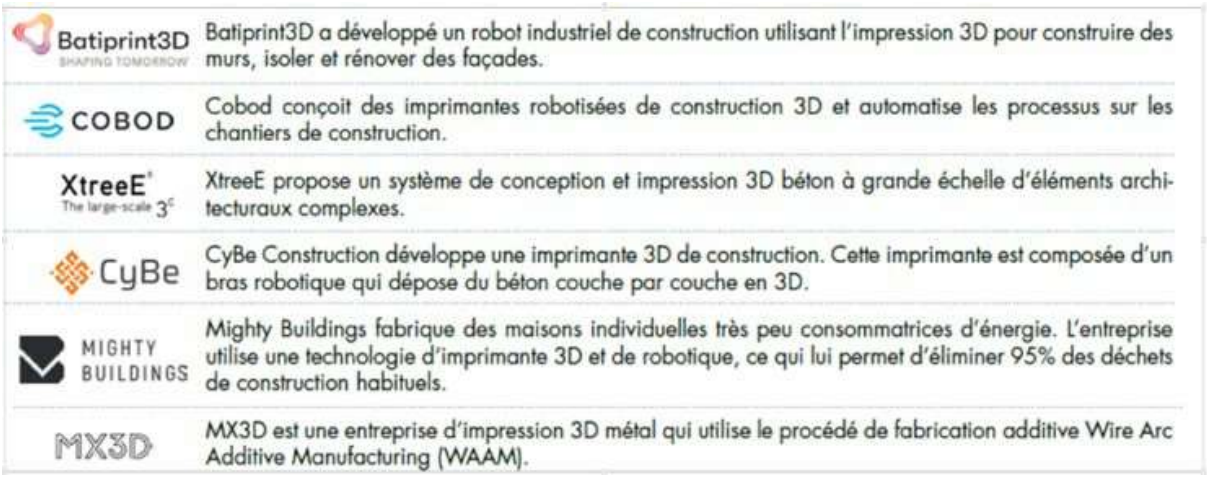


*Figure 1: Examples of 3D printer manufacturers for the construction industry (source: Observatory of building and public works innovation trends).*

But the use of 3D printing machines for construction is expensive: from €180,000 to more than one million euros. The construction is partial; it always requires manual installation of plumbing, electricity, windows, etc. Moreover, the external surface of printed houses is not as smooth as that of traditional houses. However, compared to traditional constructions, it requires much less labour.

SPIE Batignolles is also experimenting with 3D printing for small prefabricated concrete elements which are assembled afterwards at the construction site: beam nodes and reservation boxes. Therefore, 3D printing can also be an industrialisation tool off the construction site.

In conclusion, robot “tradespeople” such as 3D printers tend, a priori, to reduce the risk of occupational accidents and diseases, particularly by decreasing the work and the number of professionals required. However, they generate new risks which are quite varied. These can be related to the man-machine interface (mental overload linked to programming, screen work, possible isolation, etc.), but also the intensification of the operator’s physical load, reduction of their room for manœuvre or the repetitiveness of their movements. Added to this is the risk related to poor use of these machines. As for exoskeletons, they fall more within the framework of tools for preventing musculoskeletal disorders, provided that the work load does not increase due to a misuse of these mechanical aids to grow productivity

# 4. Risks still present

## 4.1 Uncertainties about prevention of MSDs in new build and renovation methods

With regard to the prevention of musculoskeletal disorders and lower back pain, the possible futures explored through the scenarios are hopeful but also cause for concern.


*Workers manually remove a raised floor in view of its reuse for a new construction.*

### 4.1.1 Less physical constraints at new construction sites?

In new build, the use of greater industrialisation and prefabrication can contribute to better control of work situations. In a factory or workshop, it is easier to implement technical solutions for mechanising and automating certain tasks than at a construction site. However, these solutions will have to aim to limit constraints related to lifting heavy loads, uncomfortable postures and repetitive movements.

If the leading goals are, for example, to increase production pace and limit the number of operators, it must be ensured that their implementation does not result in deteriorating work conditions, by, for example, requiring the worker to accelerate their pace to match that of the machine, or by limiting the variety of their tasks, made more repetitive.

With regard to construction phases, the development of prefabrication should lead to an increase in the volume and weight of elements to be assembled onsite and a reduction in the duration of work. We can imagine that this increase will be such that it will necessarily require the use of suitable mechanical lifting resources and should therefore decrease manual handling. Finishing phases could, for their part, be increasingly repetitive and monotonous, with operators being charged with the remaining tasks that were not able to be incorporated offsite.

### 4.1.2 More manual operations during deconstruction phases?

The development of the circular economy in the sector will mean an increase in reuse and recycling. This will transform the approach to deconstruction and rehabilitation works. Whereas demolition distances operators from certain risks through mechanical means, disassembling elements with a view to reusing them involves more manual handling. The constraints are greater if the buildings concerned were not built with the intention to be disassembled carefully later on. Innovations in prevention will therefore have be made to limit the risks associated with these operations. This could mean the use of innovative equipment suited to these tasks. Here, the use of exoskeletons can be useful provided that they are adapted to the variety of movements that workers must perform and that these workers adopt this equipment following the testing and training phases that may require some time. At the same time, design efforts must be made to improve the execution of disassembly in view of these subsequent phases. In addition, mechanical sorting of the site's waste for recycling purposes should be preferred.

## 4.2 Aiming for better consideration of the prevention of falls

Effective prevention of falls at construction and renovation sites requires, above all, the consideration of this risk as early as possible. This matter is therefore raised with regard to how to integrate this risk in the future organisation of construction and renovation worksites.

### 4.2.1 Progress expected in new build

The development of construction methods expected in the new build sector should enable better control of the risk of falls through two aspects. The use of digital construction planning tools, in particular BIM, allows for phases regarding the integration of collective protection installation to be included in construction planning. This possibility will have to be integrated into BIM tools, and perhaps become mandatory in certain situations so as to prevent the planning of worksite operations without collective protection against falls. Moreover, offsite and modular construction phases should be such that certain work at heights is avoided.

The use of greater industrialisation (possibly combined with BIM) will also mean better control of work situations involving risks, by incorporating into prefabricated modules definitive collective protection (balcony railings, woodwork) as a priority, and failing that, temporary collective protection (temporary protection of openings).

However, construction players will also be required to have solutions to manage contingencies without exposing themselves to this risk. Though they are expected to reduce the number of them, digital solutions for worksite planning will not be able to completely prevent the occurrence of unforeseen situations. Such situations often generate exposure to unanticipated risks likely to cause accidents. The capacity to manage these contingencies within the context of increasingly planned construction works, under time constraints, will be decisive in the management of the risk of falls.

### 4.2.2 Developing ways to prevent falls at renovation sites

The economic conditions surrounding the organisation of renovation operations will undoubtedly be decisive for the prevention of the risk of falls. Basically, it can be considered that the greater and more coordinated markets are, the more they will enable integration of prevention solutions, especially by organising the pooling of collective protection (scaffolding, lifting platforms, etc.). In contrast, economic models scattering renovation projects across a multitude of small, independent structures, without prevention solutions integrated by their owners, could lead to unfavourable decisions, with these structures not necessarily having the means to obtain and use satisfactory solutions on their own.

### 4.2.3 New technologies and prevention of falls: prospects and questions

Some technological innovations are particularly valuable for the prevention of the risk of falls from height. This is particularly the case when they simply eliminate the risk by not requiring operators to work at heights. For example, drones and robots can be used for inspection or checks at heights, or even for work phases (e.g. cleaning of facades or spraying of anti-mould products on roofs, etc.).

However, the increasingly frequent use of digital tools at worksites can be a factor for the risk of falls (from heights but especially same-level falls) because of their distractive nature. Smartphones, tablets, connected glasses or headphones, in drawing the attention of the operator, can contribute to lowering their vigilance concerning their environment, thus increasing the risk of collisions, trips and slips in an environment that has many hazards: troughs, tools, iron rods, etc.

## 4.3 Chemical risk through the use of new and old materials

Through the different scenarios proposed, we get an idea of the possible evolutions of the different professions involved in construction and renovation. These changes, which concern materials, organisation of production in general and of certain works in particular, can also have an influence on occupational exposure to chemical contaminants. Below is a recap of certain specific risks and/or circumstances that can promote their development or their control

*A mobile extraction system for paint, outside of a booth*

### 4.3.1 Renovation operations

They often involve the presence of old materials, some of which are of particular concern (asbestos, pigments using different chromic acids, lead, etc.) to occupational health, which the diagnostics prior to operations do not always identify. There is therefore a risk of exposure, particularly in scenario 1 where, due to the lack of economic dynamic, companies in the sector are not able to provide better-quality services compared to those of today.

Even worse, in certain scenarios, a large part of interior design is performed by individuals or handymen that are more or less professionals (or illegal workers), connected with clients through platforms. However, it can also be imagined that these platforms' actions can be beneficial if they become involved in the supply of very standardised services (for which it is easier to estimate and bill the cost), or if they invest, for marketing reasons, in the prevention of occupational risks (through, for example, the supply of drills with vacuum attachments).

This latter possibility, however, is much more likely in a context where tradespeople come together and form cooperatives with the goal of enhancing their competencies and the quality of services. But it is much more unlikely when platformisation of the activity is done to the detriment of workers.

### 4.3.2 Demolition, deconstruction, reuse, recycling

Demolition, deconstruction and stripping old buildings can generate the same risks as those described in the previous section, since no provisions were made, during construction, to facilitate and secure these operations; therefore, paint, sealants and joints can generate toxic exposure for workers. This is particularly the case when there is major determination to reuse old buildings and when workers therefore have a strong imperative to recover elements in good condition. These workers therefore probably find themselves closer to pollution emission sources. Silica is potentially a major pollutant in demolition situations.

In most cases, the reuse of elements recovered should not generate exposure seeing that any pollutants will have been treated.
The search for better reuse and recycling rates should lead to the development of targeted decontamination

operations. For example, aluminium window frames containing asbestos seals will have to be decontaminated very carefully so as to recover the glass and aluminium and avoid sending the whole frame to a landfill. These operations, which require specific facilities and competencies will be able to be transferred to specialised processing centres, where the operations can be partly automated, or performed onsite in temporary or mobile structures in order to reduce the costs for transporting large volumes of contaminated materials.

Recycling operations for uses at new construction sites, for example recycling of concrete, will increase in all of the scenarios. In order for exposure to be managed properly (to silica in particular, a real circular economy culture will have to develop and be shared by all players; exposure will have to be watched closely if it is not already the case.

### 4.3.3 "New" materials

Research has already enabled new industrial materials such as nanomaterials and self-healing concrete to be placed on the market. Currently, there is work devoted to the creation of high-performance and recyclable composite materials: this holds promise for the future.

The toxicological properties of nanomaterials are still poorly known, but the initial results give grounds for caution: this is the case, for example, with titanium dioxide considered without any risk in particular a few dozen years ago, but studies of its nanoscale forms led to it being classified as a carcinogen. The first studies devoted to the life cycle of titanium dioxide show that prevention can be organised very effectively during its manufacture and initial uses, but that prevention becomes more difficult in later stages when its size and the resources of the companies using it decrease. Then, there is the matter of dissemination in the surrounding air (admittedly in small quantities) during final uses or deconstruction and demolition operations.

As for high-performance and recyclable composite materials, specific attention must be paid to recycling operations: even though the sectors are very different (batteries and accumulators, lead waste, plastic waste), experience shows that the heterogeneity of materials often poses process problems, likely to generate occupational exposure. Similarly, materials can generally withstand recycling only for a finite number of cycles; this must also be monitored.

Significant growth in the use of bio-sourced materials in the upcoming years is a likely hypothesis. While climate conditions in France do not raise fears about the development of mycotoxins, humidity could generate endotoxins with a risk for workers during deconstruction operations. Therefore, it will be necessary to pay specific attention to the resins used to ensure cohesion of these bio-sourced materials even if they themselves are also bio-sourced (amines, epoxy, etc.).

### 4.3.4 Industrialisation and offsite construction

The working group considers that the offsite manufacture of elements that will then be assembled at construction sites, is, a priori, a step forward in terms of occupational safety and health. Thorough consideration of design matters that ensure that maintenance and cleaning operations are performed under good conditions is essential in order to avoid potentially high exposure, for example, to silica or polycyclic aromatic hydrocarbons (PACs). Therefore, an extraction device for contaminants will probably be more effective and easier to set up if planned in the design phase rather than if it is designed later on.

## 4.4 The emergence of psychosocial risks in jobs relatively spared until now

While data from the Sumer survey tend to show that construction employees are apparently less exposed to psychosocial risks, some indices suggest that it will be increasingly hard for them to avoid them in the future, for several reasons.

### 4.4.1 Digitisation

Digitisation of the sector should enable better anticipation of work situations, and if a risk assessment is conducted beforehand, contingencies and risk situations should decrease. Good anticipation should therefore be beneficial both for reducing PSRs and for improving work situations. However, certain functionalities offered by digitisation could undo these expected benefits, for example, if the project owner changes plans at the last moment, on the pretext that digitisation allows for last-minute flexibility.

Worksites are increasingly prepared ahead of construction with digital tools and a very precise distribution of tasks among operators, who sometimes wear connected equipment. In such a configuration, work and work processes become imposed, leaving operators less and less leeway to exercise what gives them their edge: managing contingencies at the worksite using their expertise. It is possible that this digitisation prevents or hinders experienced workers from resolving contingencies.

Relational difficulties among generations could also develop in the sector because of changes in the master-apprentice relationships and the growing digitisation of certain jobs (rise in home automation for example) which could pose problems for older workers. The sharing of older workers' experience with younger workers could be valued less, especially given that time pressure in construction is expected to increase while operators' room for manœuvre diminishes.

### 4.4.2 Industrialisation and prefabrication

Apart from the impoverishment of tasks which could reduce the interest of the work for the more experienced workers, assembling prefabricated modules at construction sites requires less personnel and can lead to more workers in isolation situations at the worksite. Industrialisation can also lead to the intensification of work for labourers at production sites, without them enjoying the sense of meaning that is had when seeing a construction site progress.

### 4.4.3 Circular economy

The development of a circular economy in the construction sector can be meaningful for construction workers. It can also be a factor in attracting workers from other fields. However, too much pressure to make this change can have adverse effects on workers' mental health, especially if they do not have the resources to perform high-quality work to reach the environmental goals set.

### 4.4.4 Platformisation

The potential platformisation of the sector is not neutral regarding psychosocial risks (see section 3.1.2, page 13).

### 4.4.5 Greater exposure to external violence

Until now, construction workers have been relatively protected in their relations with the public, but in the future, they could be increasingly confronted with the risk of external violence. This is particularly the case with the renovation of occupied sites, for example, social housing where, in general, the occupant is not the company's client and does not necessarily agree with the purpose of the work (and might even consider personally that priorities should be placed elsewhere). The company can then be confronted with incivilities and aggressions, with no solutions to respond to the different parties other than hiring mediators to manage the tripartite relationship between the client, the company and the building occupants. This dimension, which historically was the responsibility of social landlords, is increasingly delegated to construction companies within the framework of large contracts. Moreover, these matters can also concern traditional co-ownerships.

It can also be a matter of the development of delinquent behaviour such as material or equipment theft at worksites in response to which it can be tempting to equip construction sites with security devices that can potentially be used to monitor workers (video surveillance).

# 5. Focus on cross-cutting challenges

The last part of this exercise was devoted to the exploration of cross-cutting challenges which appear as particularly decisive in terms of work conditions and safety both for construction workers and for future players and professional users of the buildings. The working group selected three challenges: the matter of coordination among players, that of taking into account subsequent actions on buildings and that of repurposing buildings for new professional uses. None of these challenges are new. Their decisive nature in terms of prevention has been recognised for a long time, but changes to come, highlighted during the exercise, justify that they receive specific attention, with many factors possibly contributing to increasing their critical nature in the future.

The approach adopted here consisted in investigating the potentially positive and negative evolutions regarding prevention, caused by each of the scenarios. The results of these questions are presented, for each of the three challenges, in the form of tables aimed at opening up reflection and discussion.

## 5.1 The matter of coordination among sector players

Here, it is about imagining possible impacts on work conditions (particularly at construction sites) resulting from the quality of coordination and circulation of information among the different players: the project owner, the prime contractor, subcontractors, etc., but not just the matter of safety and health protection as it exists today.



*A prefabrication zone for stands at the Nice stadium construction site where several players operate at the same time.*

N.B.: In the table presented on page 41, two different notions are used:

- **organisational (or general) coordination**: it corresponds, for example, to a steering, or scheduling, steering and coordination mission (ordonnancement, pilotage, coordination - OPC), entrusted by the project owner to an OPC coordinator (often associated with the prime contractor);
- **safety and health protection coordination**: this is a specific prevention mission (prevention in the case of co-activity and organisation of resource pooling), entrusted by the project owner to a safety and health protection coordinator.

## SUMMARY

The elements compiled in the table presented on page 41 show that the quality of coordination will be heavily dependent on the economic and regulatory context governing construction sites. In some cases, coordination might be perceived as expensive and useless. In others, it might be part of a global coordination approach aimed at guaranteeing the quality of work and the achievement of environmental objectives. Increasingly large differences may be able to be seen between large and small projects.

In addition, the job of coordinator seems destined to undergo major changes in the future, the scope of which is not yet precisely determined. Digitisation and the use of technologies can transform practices. Communication through very interoperable BIM with complete integration of occupational safety and health issues is decisive. A part of the safety and health protection coordination activity could be dematerialised and integrated into BIM tools upstream, as of the design and planning phases. The practice of visiting construction sites could also evolve by using “videovisits” or inspection drones no longer requiring the presence of the safety and health protection coordinator at the site.

Other dimensions can generate changes in the job and the necessary skills to perform it. The transfer of a part of work (and risks) to the factory can mean that the safety and health protection coordinator must learn about the factory because offsite activities can also have an influence on risks at the construction site. Regular updating of skills taking into account the evolution of materials used (new components) and work methods (deconstruction, reuse, robots) must also be anticipated.

| Scenarios | Possible opportunities for prevention | Possible obstacles to prevention |
|---|---|---|
| Hard to do everything<br><br>Key prevention players: project owners for large institutional projects, prime contractor for the others. | Project owners remain limited by the challenges, particularly that of controlling costs and deadlines.<br><br>Some project owners at the forefront*, particularly institutional ones, have however become aware of the importance of coordination missions (scheduling, steering and coordination and safety and health protection) and accept to give them a role in the operation, while remaining attentive to the impact. They are therefore proactive and adopt the main prevention recommendations especially for maintenance aspects (subsequent actions on the structure).<br><br>*Such as social landlords and social housing promoters, as well as national property promoters who cut costs, but also have had to integrate the recommendations from prevention institutions, which are increasingly a mandatory requirement in contracts. | Contradictory interests of players can lead to risk situations.<br><br>Some project owners continue to neglect organisational and safety and health protection coordination missions in their operations, believing that they are making financial savings. Missions continue to be underestimated (competition), and only the major players (national) manage to get by:<br><br>– organisational coordination: project owners being limited, they hardly organise coordination (steering mission), either by letting the prime contractor's team take care of it (case of separate batches), or by choosing general companies that follow that culture; the lack of coordination increases risks at the worksite;<br><br>– safety and health protection coordination: missions remain underestimated. The major players dominate the market, but perform the missions to the minimum. Independent coordinators manage by catering to niche markets with clients that are convinced by a proactive approach to prevention.<br><br>Recruitment of safety and health protection coordinators remains difficult. A diminishment of skills is observed.<br><br>Within the framework of work for individuals (including construction of individual homes and small renovations, particularly interior design), coordination missions are not always performed (no obligations, transitory worksites, benefit not perceived and not explained to the client).<br><br>Risk prevention suffers as a result; the accident rate at construction sites remains high despite the involvement of prevention players. |
| Sustainability companions<br><br>Key prevention players: large companies and tradespeople cooperatives. | Good communication and balanced relationships between players serves to take into account each party's constraints and pool prevention resources.<br><br>The jump in energy renovation by committed players, leads them to become aware of their social accountability. Occupational risk prevention therefore also becomes a concern for construction players.<br><br>For the project owner, organisational coordination of work becomes a common practice, since it enables integration of sustainable development (management, maintenance, recycling) in a global approach.<br><br>Construction appears to have a bright future. The coordinator profession (scheduling, steering and coordination, and safety and health protection) regains its status and coordinator specialisations develop in new construction modes: new materials, bio-sourced materials, recycling/reuse, wood construction, etc. Given the increase in building specialities, this mission becomes increasingly complete and specific.<br><br>Even in operations for individuals, safety coordination is viewed as important, because it is part of a greater objective, which is to reach technical and environmental goals. | This scenario gives an important role to very small trades businesses which are known to have fewer resources for setting up structured prevention strategies.<br><br>If each company focuses only on their core business and expertise, this can cause problems in co-activity situations.<br><br>In terms of coordination, specialisation is detrimental to the global view. The principle of "to each their own specialty" results in a lack of coordination among the different players.<br><br>. |

| Scenarios | Possible opportunities for prevention | Possible obstacles to prevention |
|---|---|---|
| Industrialisation and a circular economy<br><br>Key prevention players: industrial manufacturers and lead contractors for assembly at construction sites (new job?) | Good preparation and planning of operations can reduce the duration of construction and the occurrence of contingencies.<br><br>With industrialisation of new builds developing, organisational coordination missions at the construction site are growing, with a trend towards specialisation, likely to limit (by the effect caused) co-activity at the site to facilitate its progress.<br><br>This mission becomes recurrent, if not regulatory (regulated). A speciality in safety and health protection coordination for assembling operations at the construction site develops.<br><br>Project owners surround themselves with competent and effective scheduling, steering and coordination experts. The latter make their presence essential for project owners thanks to the industrialisation of the processes in which they participate, replacing safety and health protection coordination missions by technical inspector missions for manufacturing processes (new job) and technical expertise missions at renovation-demolition-recycling sites entrusted to them by their project owners. They also enrich their competencies in prevention to the benefit of the projects they follow. Private operations for new builds develop in general construction companies to cover even deconstruction-demolition phases (circular economy) all the way up to finishing works (or even commissioning and maintenance) because these companies offer the guarantee of controlled coordination.<br><br>In public contracts, since allotment is the rule, leading institutional project owners adopt general coordination (organisational) which is effective for guaranteeing the commitments made in terms of environmental objectives, and at the same time competent safety and health protection coordination by placing confidence in the major | If coordination of players is based only on circularity goals, this can increase exposure to certain risks.<br><br>This overly specialised organisational mission focuses on savings on time and technical resources (costs, circularity goals, energy challenges) to the detriment of risk prevention.<br><br>Contrary to organisational coordination, the safety and health protection missions no longer have any real value out in the field, because worksites are finally not as complex as before.<br><br>The complexity of construction, which generated co-activity at the worksite along with risks, is transferred to a prefabrication factory and/or is managed in digital design and planning tools.<br><br>Therefore, production sites see an increase in their accident rate. Safety and health protection coordinators lose their skills; independent workers diversify their missions and only the major players maintain safety and health protection coordination.<br><br>Private operations for new buildings use a competent safety and health protection coordinator (because of a regulatory obligation), mandated by the project owner at a (very) controlled cost, but whose role remains secondary given the competencies of the general construction company which performs missions usually assigned to the safety and health protection coordinator.<br><br>For other public project owners (medium-sized and small local authorities), safety and health protection missions are not very useful because the purpose of the coordination remains general and technical. |
| Construction on digital platforms<br><br>Key prevention players: the platform and specialised independent workers. | With activity being heavily driven by digital tools, organisational coordination, when it is established, does not escape the digital realm: site visits are performed by drone or video (body camera), to generate as little travel as possible.<br><br>Safety and health protection follows the same path to remain on the market. This field sees the emergence of missions being led remotely by independent “uber-safety and health protection coordinators” Reports in the logbook draw on images and films taken from a distance. Safety and health protection regulations evolve to accommodate this. | Players downstream endure the constraints imposed by platforms focused on customer satisfaction.<br><br>In a world where new property service players are present, there is no role for organisational coordination, because it is hardly visible with regard to its value to the project. Its absence is felt only once the operation is launched (too late).<br><br>In the longer term, this lack is identified, and finally offset by operators that propose it in order to not be burdened by disputes emerging from this lack of organisational coordination.<br><br>Safety and health protection coordination is subject to market forces; these missions are incorporated into building construction services (by regulatory obligation). Safety and health protection coordinators are hardly involved at the design phase, because products are standardised, and their services have no added value. Their involvement during construction is also limited because costs remain controlled. |

## 5.2 Consideration of subsequent operations

Here, it is a matter of imagining the possible impacts on the working conditions of future building operators, whether it is repair, maintenance or cleaning operations. This concerns both new build and old buildings which undergo renovation operations.

### SUMMARY

In this area as well, the economic context and the quality of communication between players in the sector will be decisive. One of the ways to improve is through standardisation to integrate technical rules as from the construction or assembly phase, which will facilitate the maintenance and deconstruction of elements.

In this regard, the building-as-a-service model can enable progress, especially if the project owner remains the owner and manager of the building in the long term. He or she would therefore naturally tend to include these matters in their design to control operating costs afterwards. However, if repair and maintenance phases are considered as accessory because they will be outsourced to external service providers, the risk is that these phases will not be taken into account upstream.

| Scenarios | Possible opportunities for prevention | Possible obstacles to prevention |
|---|---|---|
| Hard to do everything | The fact that major players push for technification of construction processes, particularly because of the lack of labour, can make it so that the capacity to perform maintenance and cleaning operations are taken into account as from the design phase. | If communication and traceability are not good, each subsequent operation can result in bad surprises. For example, in a building insulation operation, if a company has sealed asbestos, the information about its presence must not be lost.<br>The project owner's short-term challenges create a design process with time constraints which can mean shorter design and programming phases. This could lead to situations where the project owner has few elements concerning future activities and could forget to anticipate certain activities, particularly maintenance, cleaning and renovation operations. |

| Scenarios | Possible opportunities for prevention | Possible obstacles to prevention |
|---|---|---|
| Sustainability companion. | The dominating logic of ecological reconstruction and the durability of structures is a favourable context in order for all operations (from design to end of life before renovation) to be continuously taken into account. It is a favourable scenario for servicing and maintenance operations.<br>The proximity between the prime contractor and companies is conducive to proper consideration of these challenges, particularly to preserve a high-quality commercial relationship and the reputation of the companies. Political proactivity | In this scenario, renovation dominates. Consideration of subsequent operations could be lesser in these renovation projects than it is currently in the new build sector. |
| Industrialisation and a circular economy | Prefabricated components, if they are easily disassembled, can make maintenance operations safer.<br>Industrialisation is a good opportunity to take into account the constraints related to the execution of servicing and maintenance operations under good conditions. The same goes for the growing portion of new build in the market, and for the desire for circularity: if good conditions are implemented for deconstruction, the same can | However, if they are cumbersome and do not integrate these aspects (because priorities are only to reduce costs and the carbon footprint), programmes can make these internal operations more delicate.<br>Deconstruction-reconstruction increases.<br>Reconstruction will probably be safer but risks could be present during the deconstruction phase, especially if the reuse and recycling circuits do not have a profitable economic model enabling |
| Construction on digital platforms | If the economic model shifts towards leasing (building as a service), it is in the interest of investors to integrate these issues in their programmes because they will remain owners of the buildings and will be responsible for management in the long term.<br>The logic according to which buildings must be continuously adaptable holds true if servicing and maintenance operations were correctly planned ahead. | If subsequent operations are entrusted to independent workers through platforms, this is not favourable for prevention.<br>The indication that businesses are continuously competing is also not very favourable for the prevention of occupational risks. |

## 5.3 Repurposing of buildings for new professional uses

Here, it is about imagining the possible impacts on work conditions (in particular future users) resulting from operations to reuse existing buildings to install new activities. This can be, for example, old industrial workshops transformed into offices, or the use as logistics warehouses of buildings not designed for that purpose (parking lots, for example) or third places where several activities can co-exist (coworking, fablab, recycling, etc.).


### SUMMARY

In these building repurposing situations, as in any design project, motivations are decisive for the future quality of use. According to the situation, the main goal can be:

– economic: quickly have a well-located place for example;
– aesthetical: give new life to a building whose aesthetic value is recognised;
– ecological: limit soil alteration and consume fewer resources than for new constructions;
– urbanistic: find a new use for an abandoned building.

The advantage of these approaches is that the existing building must make it possible, in advance, to study whether the activity planned is a good match for the building. The disadvantage is that room for manœuvre may be limited to obtain the goal. The characteristics of the building could jeopardise the achievement of essential objectives concerning working conditions: ventilation, natural light, circulation flow management, etc.


| Scenarios | Possible opportunities for prevention | Possible obstacles to prevention |
|---|---|---|
| Hard to do everything | The slow pace of renovation favours stability which can be favourable for people who are comfortable in a given place and do not wish to change their workplace or work situation often.<br>If the materials used are healthy, there will be no exposure to new contaminants such as formaldehyde or materials containing nanomaterials, etc. | The lack of coordination reinforces conflicts between aesthetic challenges (the architect desires a project that has character), economic challenges (the logistician wants cheap square metres in the city centre) and working conditions challenges (the employee wants a bit of natural light).<br>The solutions for improvements in work conditions remain transitory and fragile. Any new initiative for improvement will often have negative effects on the previous initiatives because of the lack of coordination and anticipation.<br>The context of the “obsolescence of the building stock” and in which “renovation mostly covers interior design rather than structural work” leads to light renovations that do not respond sufficiently to the technical requirements of the change in use. For example, acoustic and thermal mechanisms in the event of a transformation of workshops into offices or access to natural light requiring structural work in the case of a transformation of homes into offices. This has consequences on the work conditions of future users. |

| Scenarios | Possible opportunities for prevention | Possible obstacles to prevention |
|---|---|---|
| Sustainability companions | In this scenario, the project owner manages to ensure a long-term and even global vision (including the occasional project owner who receives support). Specific attention is paid to the adaptation of the building to the needs of future occupants.<br><br>The creativity and initiatives left to micro-enterprises lead to the implementation of renovation solutions adapted to the particularities of the building. The reuse of the materials in place limits waste and the need for new materials.<br><br>Thanks to the increased expertise of the project owner, the solutions for the improvement of work conditions (acoustics, ventilation, natural lighting, etc.) fit simply and seamlessly in the existing building. | The highlight is placed on the frugality of the project to the detriment of renovations enabling better work conditions.<br><br>The considerable share of renovation compared to new build can reduce leeway for adapting the building to future uses.<br><br>The importance given to the technical aspects (reuse of materials, energy performance requirements, etc.) risks concealing the matter of the use and the match between renovations and new activities. |
| Industrialisation and a circular economy | Industrialisation reduces risks at worksites, since products are designed according to standards that integrate prevention (elimination of risks related to falls, improvement of lifting conditions, etc.).<br><br>Future users are less affected by a renovation or extension project, because they take less time and are better apprehended in terms of risk prevention. | Heavy renovation or reuse of materials, once carcinogenic, mutagenic and reprotoxic (CMR) products are present, such as asbestos, lead, silica, etc., has negative consequences on the work conditions of the worksite employees but also on future users if work is not performed based on standards. The confinement of work areas (decontamination) remains an imperative for avoiding the spread of contaminants). |
| Construction on digital platforms | Rehabilitation is performed by investors for the purpose of leasing; this can encourage modularity which would enable the layout to be adapted to the needs of occupants.<br><br>The very high degree of building modularity enables spaces to be adapted to very different configurations and uses. The basic criteria (lighting, acoustics, heating, outside view, artificial lighting, etc.) will be systematically met but often to the minimum. | In the case of low-cost leasing, and for short periods, tenants will have to adapt to the building or leave it. Short renting time can lead to compromises concerning the comfort of use.<br><br>Over-standardisation leads to tiring repetitiveness of living and work spaces.<br><br>Specific needs related to a particular activity risks not being taken into account, on the grounds that the versatility of places exempts the designer from adapting them to uses. |

# Conclusion

This prospective exercise is the product of two collective work efforts which were conducted from 2019 to 2022. First, CSTB and Ademe created and led a group of 17 people to produce the toolkit “Imagining together the buildings of tomorrow”. Second, INRS followed suit with a group of 12 people who took up this topic to explore the occupational safety and health challenges more precisely. Here, we would like to acknowledge all those who took part in this exercise.

As always with prospective exercises and in particular in this document, the goal is not to “predict the future”, but rather to propose narratives to allow for projection into the future and to highlight challenges in order to spark reflection and debate. It therefore has a collective target; it aims to encourage players to take up the subject to fuel their strategic questions. Its goal will be reached if it leads to people’s concerns being better taken into account by other people.

The magnitude of the changes to come in the building sector and the diversity of forces generating them increasingly require, now more than ever, dialogue among players so that some players’ priorities do not impose harmful limits on others, and especially so that they do not have consequences on operators’ health. Digitisation, ecological transition, industrialisation: each of these phenomena presents opportunities to improve work conditions. To reinforce this hope, it is important for these aspects to be present in the minds of all sector players when they make decisions that can, directly or indirectly, in the short or long term, have an impact on workers’ safety and health.

# Methodological annexes

## 1. Key variables, summaries and hypotheses[19]

### • Occupation of non-residential buildings

#### Summary

The main transformation trend in the French economic fabric over the last 50 years has been the expansion of its tertiary sector, combined with the "servicialisation" of the economy and the development of the consumer society, leisure activities and free time.

These transformations have had an effect on demand for non-residential buildings: drop in the construction of industrial facilities, rise in the construction of offices and stores (which are now the two leading sectors in terms of surface area in the tertiary building stock). The other sectors have developed based on the demographics and planning of the territory. For example, education surfaces have grown significantly.

Office spaces are confronted with recent transformations, under the effect of digital technology in particular. Work is being automated, and can increasingly be conducted remotely. Commerce is also undergoing considerable changes: development of e-commerce and logistics, drop in the appeal of hypermarkets, increase in the vacancy rate, but increased activity in local stores, and adaptation of commercial offers (shopping centres' shift towards leisure activities).

Ageing brings health-related needs, but part of these needs are catered to in the home.

#### Prospective hypotheses

**1. Stagnation**

The phenomena already observed continue, i.e. the change in the use of surfaces goes hand in hand with changes in the activity.

Each sector keeps its square metres but modifies the uses.

Office spaces become rooms for meetings, seminars; shopping centres become showrooms and places of entertainment, etc.

**2. Crisis in the service industry**

The explosion in remote work and e-commerce leads to a drop in demand for office and shop surfaces. There are no new needs that emerge enabling a reassignment of surfaces, or the change in use is hard to achieve. Vacancy increases and prices fall.

**3. New dynamic**

New sector configurations result in a drop in needs for office and store space.

Prices fall and allow a part of these surface areas to be used for new commercial and non-commercial activities.

Some buildings can become logistics centres or accommodate activities that are part of the social and solidarity economy and/or the circular economy (recycling centres, repair facilities, urban agriculture, etc.) or relocated industries.

*19. These elements stem from the "Imagining together the buildings of tomorrow" approach and are directly taken from the website: https://www.batimentdemain.fr/ where the reader can access the complete variables sheets.*

## • Technical policy

### Summary

These policies, which, for several centuries now, primarily covered safety, have expanded over the last few years to include environmental, health and social challenges in the longer term.

New buildings' energy consumption has been regulated since the 1970s. Regulations concerning existing buildings is being developed, but they struggle to reach the objectives which are extremely ambitious.

Health challenges, consideration of lifecycle, performance obligation, long-term performance, mutability and reversibility of spaces, etc., new challenges could drastically redefine technical rules in the future.

Technical policies have a long-standing tradition of formalising customary constructive rules (state-of-the-art), which they do by combining "hard law" and "soft law" (voluntary standards such as NF standards and labels).

The great diversity in the topics addressed complicates these rules, and can cause contradictions. It requires thorough preparation of laws (cost/benefit analysis in particular), which is not always performed and causes texts adopted to be challenged.

The emergence of a European decision-making level complicates things even more.

### Prospective hypotheses

**1. Patchwork of technical rules**

The poorly regulated weight of numerous lobbies leads to the multiplication of rules that are inconsistent with each other. This causes poor optimisation of constructions and renovations, an increase in disorder and non-compliance with rules, etc.

Technical policies do not reach their objectives.

**2. Quality of new build and renovation**

A series of negotiated and coherent rules provides a shared framework for players that follow it. This framework accompanies the transformation of new constructions and renovation of the building stock to reach targets set, particularly in terms of sustainable development.

**3. Quality of new build**

In the new build sector, the coherency of rules allows for progress in the quality and achievement of objectives pursued, but the technical policies struggle to make the existing stock move forward, except for large operations.

## • Obsolescence management

### Summary

Since the end of the Second World War, many obsolescence factors have come into play. Economic developments (growth of the service sector) and territorial changes (urbanisation), crossed with the change in techniques, have made agricultural and industrial facilities obsolete. This obsolescence was dealt with either through vacancy, destruction or a change in use.

The change in social standards for housing (comfort, hygiene) was addressed by adapting the existing building stock (development of bathrooms, toilets, central heating).

New construction has also been a pillar in the management of the obsolescence of unhealthy homes. The large housing developments of the 1970s quickly became obsolete, in connection with the functioning of the city, and debates exist concerning the best strategy for managing this obsolescence (destruction, renovation, etc.).

The change in commerce has led to vacant shops in the town centre, especially in medium-sized towns. Obsolescence of offices accelerates, under the effect of work changes and companies' strategies to manage building stocks.

As from the first energy crisis of 1973, energy performance has become a factor of obsolescence. Energy renovation policies struggle to accelerate the pace to overcome this issue.

Other emerging factors that will contribute to future building obsolescence: ageing of the population (and the taking into account of disability) and climate change.

### Prospective hypotheses

1. **Slow renovation**

The market share of new build and maintenance/renovations maintains its historic trend. The integration of new requirements in the building stock takes place slowly, just like the integration of comfort features: bathrooms, toilets and heating, which took over a half-century to be implemented. This slowness in renovations means that the building stock is comprised of both buildings that have been upgraded and adapted to new requirements, along with buildings that are becoming increasingly obsolete.

Market shares for new build and maintenance/renovations remain stable. If the change in obsolescence factors is fast and renovation is slow, there can be increased obsolescence of the building stock which no longer follows the change in demand.

**2. Fast renovation**

Faced with the major and fast loss in value related to obsolescence factors, new models develop to massify the renovation of existing buildings and their change in use.

Supply-side players up their game in this market: current renovation players, new build players that undergo transformations and new players.

New economic models often make renovation more attractive than new construction.

Building renovation appears as an attractive solution for demand-side players. New construction is focused in areas where demographic pressure is high. New buildings are built to be adaptable. Market share of new build declines.

**3. New Hausmannian drive**

Competitiveness of new build in terms of quality/price/deadline/environmental performance makes it more attractive than renovation.

Obsolescence is managed preferably by the loss in value of obsolete buildings, a growing part of which become vacant (mostly in low-demand areas), is demolished (in high-demand areas) or is used by those seeking low-cost spaces. The market share of new build increases.

## • Quality of use of buildings

### Summary

Safety, comfort and hygiene are central social standards in the building sector. They change. For example, comfort no longer comes down to just purely technical criteria, it is also synonymous with protection, well-being and personal fulfilment.

The qualities desired by occupants evolve and multiply: quality of indoor air, acoustic comfort, and increasingly, ecology.

In housing, the idea of having personal space is a requirement, creating tensions between optimisation of space and need for privacy, in a context where internalisation of activities (work, leisure) has changed our relationship with housing.

Modelling spaces to suit one's image becomes essential. In connection with ageing, adaptation has become synonymous with independence, neglecting the need for customisation and control. Quality is increasingly standardised, based on criteria or labels, but the difference between aspirations and standards widen. Tensions appear between regulatory requirements and quality of use (desynchronisation of behaviour and activities).

### Prospective hypotheses

#### 1. Furnishings and equipment

Buildings lack flexibility and struggle to adapt to the diversity in demands (comfort, privacy, evolution of work, etc.) which are asked of them. In this context, occupants organise their spaces with furnishings and equipment that they adapt based on their needs. In housing, for example, after the kitchen, bathroom, closet, etc., adaptation of furnishings continue. The equipment selected by occupants multiplies (air purifiers, home cinema, etc.). When occupants reach the limits of the adjustments they can make with furnishings, and when they are able to, they move out, to adapt the building to their new needs. For example, young families swap apartments for houses, businesses change locations.

#### 2. Pictures and plants

Buildings lack flexibility and are standardised, but occupants tolerate them because they can adopt spaces without requesting major changes to the building or because they do not have the possibility to do otherwise. They put up with standardised spaces that they customise to their liking by carrying out small touch-ups (painting, pictures, green plants). If new needs emerge, occupants prefer to change spaces completely rather than make adjustments. For example, young people start their working life in co-living spaces, which they then leave for a larger space when they have families, or, in the case of separations, they go towards flatshares designed for single-parent families. Businesses move from a specialised space (coworking, shared meeting rooms, etc.) to another depending on their needs.

#### 3. Walls adapt to demand

The flexibility of buildings and spaces becomes the watchword in the property market, and faced with the increasingly diversified demands of occupants, design, construction and renovation methods undergo profound changes. Apart from extensions of individual houses, which are already widespread, buildings are designed to enable adaptation to specific needs and to their evolution. New constructions and major renovations get future occupants involved. The techniques used facilitate restructuration of spaces.

## • Organisation of the construction/renovation sector

### Summary

The construction/renovation sector undergoes different evolutions:

- multiplication of players, subcontractors and decrease in the coordinator role of the prime contractor;
- decrease in productivity (price, quality) of the sector compared to other sectors;
- change in increasingly sophisticated industrial projects and growth of their share in the value of projects;

- increase in building requirements concerning the environment, comfort and health. Tendency towards performance obligations and not only resource requirements;
- development of BIM as a tool that can potentially contribute to better coordination;
- development of offsite construction in certain sectors, sometimes abroad.

### Prospective hypotheses

**1. Stagnant productivity**

The sector continues to function similar to the current situation and does not solve its productivity issues.

The many players in the sector fight to obtain most of the value-added without there being any progress in the quality and the collective value-added.

New tools such as BIM generate competition among players and do not reach their target for improvements in coordination.

**2. Collective improvement**

Players become aware of their capacity to collectively increase their efficiency through better collective coordination. In particular, they draw on digital tools to facilitate this coordination. This results in a drop in poor workmanship and an improvement in their margins.

**3. Power to coordinators**

At different types of worksites, players take up the role of conductor in ensuring collective coordination. These coordinator players capture a growing portion of the value-added .

Players in this coordinator role vary based on the type of worksite: major players for large complex projects, organised individual home developers, renovation platforms, etc.

This coordination does not exclude industrialisation of production, but it is the players downstream that steer projects.

**4. Industrialisation**

A significant portion of value-added is transferred from the worksite to the factory. It is manufacturers that capture the value-added.

Complex prefabricated components and offsite construction develop. Coordination is based on products, with the worksite becoming a place of assembly for industrial products.

This industrialisation reduces construction times and disorder at the worksite. It can be promoted by digital technology. It has a major impact on the types of jobs needed and their location. It can cause offshoring of a considerable part of the building market to a European or extra-European country.

## • Materials produced and equipment

### Summary

The history of the building industry is that of the growing complexification of materials being used in design, and the multiplication of products and equipment circulating between countries in a market becoming globalised.

Over the last 30 years, there has been a global improvement in the energy performance of equipment and products, however without any major breaks in the technical renovation solutions. Measurement of the carbon footprint of products has become widespread.

The healthiness of construction products has been a priority for several years. Asbestos is the most publicised example of this.

The last decade has also seen the emergence of public policies specific to building resources, structured around waste management in the building and public works sector, which then broadens to introduce the notion of circular economy.

Faced with partly globalised production, over the last few years there has been a major tendency towards the development of frugal and local products, bio-sourced in particular.

A recent evolution in the market is the appearance and development of connection equipment and the Internet of objects.

## Prospective hypotheses

### 1. Technicisation

Materials produced and equipment become increasingly technical.

Work on the fine structure of materials leads to technological innovation: super-insulating, self-cleaning, self-repairing products, switchable glass, etc.

Construction products and equipment digitise and become connected, which enable their operation to be adapted automatically, their maintenance to be followed, etc.

This technicisation can lead to an acceleration of product obsolescence.

Technicisation also aims to facilitate employment at new construction and renovation worksites, one of the challenges being to obtain technical, but easy-to-install products.

### 2. Circular economy

Circular economy becomes widespread in construction.

Manufacturers set up supply chains for recycled materials and get involved in the recovery of their products at the end of their life cycle.

The reuse of products develops and becomes the basic solution for certain types of products which are designed to be used successively in several buildings.

Some products are no longer sold but are leased. Product lifetime lengthens.

The systems for characterising products and insurance evolve so that the performance of products can be traced all throughout their lifetime and risks related to reuse and recycling can be controlled.

### 3. Frugality

Construction increasingly uses bio-products, geo-products and local products. Minimally processed and local products appear as effective means to respond to pressure on resources and to reduce the carbon footprint, but also to develop the local economy.

Their use results in exceptional projects and becomes widespread.

Materials used historically (mainly concrete, cement, brick, steel and glass) evolve. They are used sparingly based on the principle of the right material at the right place. They reduce their carbon impact by changing the energy used and their production process. They highlight their integration into the national or local economy.

## • Labour in the building and public works sector

### Summary

A million and a half people work in the building and public works sector. It is a very male-dominated sector (88% male), not very attractive (except for skilled jobs) and struggles to retain seniors.

Working conditions have improved. Between 1955 and 2008, the number of occupational accidents in the sector was cut by half, but jobs continue to be arduous.

This sector has always used immigrant workers, especially during the thirty-year boom period following the Second World War. Since the 1990s, use of posted work has increased, and over the last decade, the sector has lost practically 250,000 jobs.

Several seeds for change have been planted in the profession, in particular, environmental challenges and digitisation.

The boom in digital platforms in the B to C finishings field holds the promise of major transformations for tradespeople.

The sector's training dynamic does not appear to be at the level of the challenges that will emerge in the upcoming years.

### Prospective hypotheses

**1. Polarisation of the labour market**

Transformations in construction and renovation modes cause jobs to become polarised. Highly skilled and well-paid jobs develop to support digitisation (BIM, CAO, etc.) and new environmental standards (sectors using bio-sourced materials, HQE, positive-energy buildings, etc.). At the other end of the chain, there is still a need for low-skilled labour for handling, installation and deconstruction tasks which cannot be automated. There tends to be a drop in intermediary jobs because of the shortening of the duration of projects and increased use of digital technology to steer work.

**2. Labour crisis**

Recruitment difficulties worsen in the sector. Companies cannot find workers with the qualifications they seek to meet their new challenges. Against an economic crisis and strong competition, they use fallback situations which exacerbate matters even more: industrial relocation, platformisation of trades, development of posted work, illegal work and do it yourself. However, niche markets do not follow this spiral.

**3. The sector becomes attractive**

The sector manages to renew its image, and, against rising unemployment, becomes increasingly attractive. Major training efforts are pursued with efficient coordination among players. The building and public works sector becomes a major avenue for professional opportunities, particularly for young people seeking to find meaning, and for workers undergoing job transitions.

Trades jobs are attractive because of their concrete and increasingly technical nature, both in local and bio-sourced sectors and in increasingly technical and connected jobs.

In large companies, career prospects, wages and continuous training efforts are very attractive. Industrialisation and investment in prevention mechanisms make jobs less arduous and more "fun", which attracts young people and women.

## 2. Morphological scenario construction box

In this box, the variables adopted appear in the first column, and on the same lines the different hypotheses about the future. The colour and typographical codes represent the combinations of hypotheses corresponding to each of the four scenarios. These scenarios are given in the last line.

| Variables | H1 | H2 | H3 | H4 |
|---|---|---|---|---|
| Occupation of non-residential buildings | Stagnation | *Tertiary crisis* | New dynamic | |
| Technical policy | Patchwork | Quality of new build and renovation | *Quality of new build* | |
| Obsolescence management | Slow renovation | Fast renovation | *New Haussmannian drive* | |
| Quality of use | Furnishings and equipment | *Pictures and plants* | Walls adapt to demand | |
| Organisation of the sector | Stagnant productivity | Collective improvement | *Power to coordinators* | *Industrialisation* |
| Material and equipment | Technicisation | Circular economy | Frugality | |
| Labour | *Polarisation of the labour market* | Labour crisis | Promising sector | |
| Scenarios | Hard to do everything | Sustainability companions | *Industrialisation and circular economy* | Construction on digital platforms |

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