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Local-to-Global-rigidity of lattices in $\text{SL}_n(\mathbb{K})$

Amandine Escalier

January 6, 2023

Abstract

A vertex-transitive graph $\mathcal{G}$ is called *Local-to-Global rigid* if there exists $R > 0$ such that every other graph whose balls of radius $R$ are isometric to the balls of radius $R$ in $\mathcal{G}$ is covered by $\mathcal{G}$. An example of such a graph is given by the Bruhat-Tits building of $\text{PSL}_n(\mathbb{K})$ with $n \geq 4$ and $\mathbb{K}$ a non-Archimedean local field of characteristic zero. In this paper we extend this rigidity property to a class of graphs quasi-isometric to the building including torsion-free lattices of $\text{SL}_n(\mathbb{K})$. The proof is the occasion to prove a result on the local structure of the building. We show that if we fix a $\text{PSL}_n(\mathbb{K})$-orbit in it, then a vertex is uniquely determined by the neighbouring vertices in this orbit.

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1 INTRODUCTION

A recurring theme in geometric group theory is that local properties of an object can have global implication for its geometry. A classical example is given by Lie groups and their locally defined Lie algebras. Another striking illustration is provided by the work of Tits \cite{Tit81} who gave a local characterization of a particular family of graphs called “buildings of type \( \tilde{A}_{d-1} \)” (see Section 2.1 for a definition). Precisely, graphs and their local-to-global properties are the objects we focus on in this article. All graphs will be equipped with the usual metric, fixing the length of an edge to one.

A natural local condition to impose on a graph is to be \( d \)-regular for some \( d \in \mathbb{N} \), which means that all the vertices must have degree \( d \). A well-known result about such a graph is that the \( d \)-regular tree is its universal covering. This is a first example of a global information deduced only by a local knowledge of the graph.

One can now ask what happens if we impose a local condition which is stronger than \( d \)-regularity. We formalize this in the next definition.

**Definition 1.1**

Let \( R > 0 \) and let \( X \) and \( Y \) be two graphs.

We say that \( Y \) is **R-locally** \( X \) if every ball of radius \( R \) in \( Y \) is isometric to a ball of radius \( R \) in \( X \).

If \( Y \) is \( R \)-locally \( X \) and \( X \) is \( R \)-locally \( Y \) then we say that they are **R-locally the same**.

**Example 1.2.** In the following example, \( B_X(x_0, 2) \) is isometric to \( B_Y(y_0, 2) \).

The previous covering result on the \( d \)-regular tree is a first example of a more general notion called the **Local-to-Global rigidity**, also named **LG-rigidity**.

**Definition 1.3**

Let \( R > 0 \). We say that \( X \) is **Local-to-Global-rigid at scale** \( R \) (or \( R \)-LG-rigid for short) if every graph \( Y \) which is \( R \)-locally \( X \) is covered by \( X \).

We say that a graph \( X \) is **LG-rigid** if there exists \( R > 0 \) such that \( X \) is \( R \)-LG-rigid.
Example 1.4. Benjamini and Ellis [BE16] showed that for any $d \geq 2$ the Cayley graph of $\mathbb{Z}^d$ endowed with its usual generating set is 3-LG-rigid. They also proved that 3 was optimal showing that $\mathbb{Z}^3$ is not LG-rigid at scale 2.

Example 1.5. De la Salle et Tessera [dlST19, Theorem C] proved that every cocompact graph quasi-isometric to a tree is LG-rigid.

Benjamini [Ben13] and Georgakopoulos [Geo17] conjectured that any Cayley graph of a finitely presented group is LG-rigid at some scale $R > 0$. That conjecture was proven to be false in [dlST19, Theorem B], where the authors built counterexamples using groups with torsion elements.

Counter-example 1.6. The groups $F_2 \times F_2 \times \mathbb{Z}/2\mathbb{Z}$ and $SL_4(\mathbb{Z})$ admit Cayley graphs that are not LG-rigid.

Remark here that we do not state that every Cayley graph of these groups is non-LG-rigid, but that each group admits a non-LG-rigid Cayley graph. Indeed, in [dlST19, Theorem J] the authors also showed that every finitely presented group with an element of infinite order has a Cayley graph which is LG-rigid. Hence, LG-rigidity for a Cayley graph depends on the generating set. In particular LG-rigidity is not invariant under quasi-isometries.

With a little bit more of material, we will be able to give a topological interpretation of Local-to-Global rigidity (see page 11).

That rigidity notion can be refined in what is called the Strong Local-to-Global rigidity, also named SLG-rigidity.

Definition 1.7
Let $r, R > 0$. We say that $X$ is **SLG-rigid at scale** $(r, R)$ if for all $Y$ which is $R$-locally $X$ and for all isometry $f$ from $B_X(x, R)$ to $B_Y(y, R)$, the restriction of $f$ to $B_X(x, r)$ extends to a covering of $Y$ by $X$.

We say that $X$ is **SLG-rigid** if there exist two radii $r$ and $R$ such that $X$ is SLG-rigid at scale $(r, R)$.

Such a refinement is far more than just a subtlety: it actually proves necessary to obtain our main result (see page 26 for more details).

The following proposition gives us many examples of SLG-rigid graphs.
Proposition 1.8 (de la Salle, Tessera [dlST19, Proposition 3.8])

A graph with cocompact isometry group is LG-rigid if and only if it is SLG-rigid.

For example, any LG-rigid Cayley graph is actually SLG-rigid. In the same article, de la Salle and Tessera proved a powerful condition relating to the isometry group of a Cayley graph. We will refer to the isometry group of a Cayley graph \((\Gamma, S)\) as Isom\((\Gamma, S)\).

Theorem 1.9 (de la Salle, Tessera [dlST19, Theorem E])

Let \(\Gamma\) be a finitely presented group and \(S\) be a symmetric generating set and denote by \((\Gamma, S)\) the corresponding Cayley graph. If Isom\((\Gamma, S)\) is discrete, then \((\Gamma, S)\) is SLG-rigid.

As stated in [dlST19, Corollary F], we can deduce two new classes of examples from the above theorem. But before, let us introduce what we call \(LG\)-rigid groups.

Definition 1.10

We say that a finitely presented group is \(LG\)-rigid (resp. SLG-rigid) if all its Cayley graphs are LG-rigid (resp. SLG-rigid).

Example 1.11. Torsion-free groups of polynomial growth are SLG-rigid.

Example 1.12. Torsion-free, non-virtually free lattices in connected simple real Lie groups are SLG-rigid.

So far, the graphs chosen as examples are mostly Cayley graphs, but these are not the only LG-rigid ones. Indeed, besides the case of quasi-trees seen above, another interesting example is given by Bruhat-Tits buildings (see Section 2.1 for a definition).

Theorem 1.13 (de la Salle, Tessera, [dlST16, Theorem 0.1])

Let \(K\) be a non-Archimedean local skew field.

If \(K\) has positive characteristic and \(n \geq 3\), then the Bruhat-Tits building of \(\text{PSL}_n(K)\) is not LG-rigid.

If \(K\) has characteristic zero and \(n \geq 4\), then the Bruhat-Tits building of \(\text{PSL}_n(K)\) is SLG-rigid.

Keeping in mind the above theorem, consider the following question asked in [dlST19].

Question 1.14. Among lattices in semi-simple Lie groups, which ones are \(LG\)-rigid?

This question concerns real Lie groups but one can also wonder what happens for the \(p\)-adic case. Indeed, by a well known result of Svarc and Milnor, any lattice of \(\text{SL}_n(K)\) is quasi-isometric to the associated building (see Lemma 5.2 for more details). The fact that such a lattice is “almost” a building encouraged us to study the \(p\)-adic version of Question 1.14.
1 Introduction

Question 1.15. Among lattices in \( p \)-adic Lie groups, which ones are LG-rigid?

De la Salle and Tessera showed [dlST16] that if \( K \) has positive characteristic, then there exist \( p \)-adic lattices that are torsion-free, cocompact but not LG-rigid.

Example 1.16. Let \( n \geq 3 \). There exists a torsion-free cocompact lattice in \( \text{PGL}_n(F_p) \) that is not LG-rigid.

When \( K \) is a non-Archimedean local skew field of characteristic zero, an element of response to Question 1.15 is provided by our first result hereunder.

Theorem 1.17

Let \( n \neq 3 \) and \( K \) be a non-Archimedean local skew field of characteristic zero.

The torsion-free lattices of \( \text{SL}_n(K) \) are SLG-rigid.

This result is actually a corollary of our main theorem below which goes beyond the lattices framework and gives a rigidity result in a more general case.

Theorem 1.18

Let \( n \neq 3 \) and \( K \) be a non-Archimedean local skew field of characteristic zero. Let \( X \) be the Bruhat-Tits building of \( \text{PSL}_n(K) \) and \( X \) be a transitive graph. If \( X \) verifies that

- There is an injective homomorphism \( \rho \) from Isom\((X)\) to Isom\((X)\) such that \( \rho(\text{Isom}(X)) \) is of finite index in Isom\((X)\);
- There is a Isom\((X)\)-equivariant injective quasi-isometry \( q \) from \( X \) to \( X \);

then \( X \) is SLG-rigid.

Let us discuss the hypothesis, starting with the assumption made on \( n \). If \( n = 2 \) then \( X \) is the \((p + 1)\)-regular tree, thus by Example 1.5 any graph quasi-isometric to \( X \) is LG-rigid which proves the theorem. Now, as we will see in the sketch of the proof, the main tool of our demonstration is the LG-rigidity of the building. But if \( n = 3 \) the question of the rigidity of \( X \) is still open. Indeed in that case a lot of flexibility seems to be allowed (see [BP07]). Thus our demonstration deals mainly with the case where \( n \geq 4 \).

Secondly, let us look at the hypothesis made on the characteristic of \( K \). According to [dlST16, Theorem 0.4] and more precisely according to its proof, we get Counterexample 1.19 below. It implies in particular that if we omit the characteristic zero hypothesis, then Theorems 1.17 and 1.18 are not true.

Counter-example 1.19. There exists a non-LG-rigid torsion-free cocompact lattice in \( \text{PGL}_n(F_p((T))) \).

Finally, before moving to the sketch of the proof let us discuss the hypothesis made on the torsion in Theorem 1.17. First, introducing torsion in a group is in some case a useful way to build non-LG-rigid graphs. Indeed the Counter-example 1.6 is built this way. Second, in order to link \((\Gamma, S)\) to \( X \) we will need an injection of Isom\((\Gamma, S)\) into Isom\((X)\). Using a famous result of Kleiner and Leeb we will show that Isom\((\Gamma, S)\) acts on the buildings by isometries. The injection into Isom\((X)\) will then be allowed by the following proposition.
Proposition 1.20 (de la Salle, Tessera [dlsT19, Proposition 6.2])

Let $\Gamma$ be an infinite, torsion-free, finitely generated group and let $S$ be a finite symmetric generating subset of $\Gamma$. Then the isometry group of $(\Gamma, S)$ has no non-trivial compact normal subgroup.

For more details on how we use this proposition, see the proof of Lemma 5.3.

**Sketch of the proof of the theorem**  As stated in the discussion below Theorem 1.18, the proof deals mainly with the case where $n \geq 4$. So, Let $n \geq 4$ and $K$ be non-Archimedean local skew field of characteristic zero and denote by $\mathcal{X}$ the Bruhat-Tits building of $\operatorname{PSL}_n(K)$. Let $X$ be the studied graph and $Y$ be a graph $R$-locally the same as $X$ and denote by $q$ a quasi-isometry from $X$ to $\mathcal{X}$. The main idea of the proof is to use the rigidity of $\mathcal{X}$ to build the wanted covering from $X$ to $Y$ (see Figure 2), thus we need to build a graph locally the same as $\mathcal{X}$. We will denote such a graph $Y$.

Moreover, for the rigidity of the building to induce a covering between $X$ and $Y$, we want $\mathcal{X}$ to contain a copy of the vertices of $Y$. Hence the goal is to define the vertices of $\mathcal{X}$ to be composed of the vertices of $Y$ and a copy of each vertex in $\mathcal{X} \setminus q(X)$ and define the edges to correspond to edges in $X$. With such a description $Y$ is a “hybrid” graph and to define its edges we might need to understand how to link a vertex coming from $Y$ to a vertex coming from $\mathcal{X}$. Hence, to avoid such a hybridation we chose to define the vertices only with informations encoded in $Y$. That is why we introduce the notion of *print* in the building (see Section 3.1). It allows us to characterize a vertex in $\mathcal{X}$ by a set of neighbouring vertices in $\text{im}(q)$ and, using a well chosen set of isometries from $Y$ to $\mathcal{X}$, to transfer this print notion to $Y$. Each print in $Y$ corresponds to a vertex in $\mathcal{X} \setminus q(X)$. The vertices of the wanted graph $Y$ will be composed of the vertices of $Y$ and of prints in $Y$. It will now be easier to build edges between these vertices; the key argument to construct such edges is presented in Section 2.3.

Using the rigidity of the building we will obtain an isometry between $\mathcal{X}$ and $Y$. To conclude the proof we will show that this isometry induces the wanted covering between $Y$ and $X$. 
2 Framework

The first section is devoted to the definition of our framework. We recall some material about Bruhat-Tits buildings and large scale simple connectedness and present a fundamental result on isometries’ extension. The second and third sections are devoted to the proof of Theorem 1.18. In the second section we develop the necessary engineering to build a graph locally the same as the building —this is where we define and study prints— while in the third one we use the rigidity of the building to prove the rigidity of the studied graph. We prove Theorem 1.17 in the fourth section where we check that the lattice verifies the hypothesis of our main theorem.

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2 FRAMEWORK

Let us start by setting up the framework of the next sections. We first recall some material about Bruhat-Tits buildings, and large scale simple connectedness. Then we present a useful tool concerning the extension of isometries. We conclude by a result one step further in to the proof of our main theorem, linking the \( \text{PSL}_n(K) \)-orbits in the building and the image \( q(X) \) of the graph studied.

2.1 Bruhat-Tits building

Let \( n \geq 2 \). Since it is the object at the center of our proof, let us recall the description of the Bruhat-Tits building associated to \( \text{PSL}_n(K) \) where \( n \geq 2 \), see [AB18] for more details.

**Non-Archimedean Local Skew Fields** Let \( K \) be a field (not necessarily commutative). A *discrete valuation* on \( K \) is a surjective homomorphism \( v : K^* \to \mathbb{Z} \) satisfying \( v(x + y) \geq \min\{v(x), v(y)\} \) for all \( x, y \in K^* \) such that \( x + y \neq 0 \). If \( K \) is endowed with such a valuation, we can extend \( v \) on all \( K \) by setting \( v(0) = +\infty \). We say that \( K \) is a *non-Archimedean local skew field* if it is locally compact for the topology associated to a discrete valuation.

**Example 2.1**. If \( K = \mathbb{Q} \) and \( p \) is a prime, then every \( x \in K \) can be written as \( x = p^n a/b \) where \( a \) and \( b \) are integers non-divisible by \( p \). The map defined by \( v(p^n a/b) := n \) is a discrete valuation over \( K \). The field \( \mathbb{Q}_p \) is the completion of \( \mathbb{Q} \) with respect to the \( p \)-adic absolute value defined by \( |x|_p = p^{-v(x)} \).
Example 2.2. Let $\mathbb{K} = \mathbb{F}_p((T))$, the field of formal Laurent series over $\mathbb{F}_p$. Denote by $f = \sum_{k \in \mathbb{Z}} a_k T^k$ an element in $\mathbb{F}_p((T))$ then the map defined by $v(f) := \min\{k : a_k \neq 0\}$ is a valuation over $\mathbb{K}$.

Let $\mathcal{O}$ denote the ring of integers of $\mathbb{K}$ with respect to $v$, that is to say $\mathcal{O} := \{x \in \mathbb{K} : v(x) \geq 0\}$. This ring has a unique prime ideal $\mathfrak{m} := \{x \in \mathbb{K} : v(x) > 0\}$. Finally, let $\pi$ be a generator of $\mathfrak{m}$ as an $\mathcal{O}$-module.

Example 2.3. If $\mathbb{K} = \mathbb{Q}_p$ then its ring of integers is $\mathcal{O} = \mathbb{Z}_p$. Moreover $\mathfrak{m} = p\mathbb{Z}_p$ and $\pi = p$.

Example 2.4. If $\mathbb{K} = \mathbb{F}_p((T))$ then $\mathcal{O} = \mathbb{F}_p[[T]]$. Moreover $\mathfrak{m} = X\mathbb{F}_p[[T]]$ and $\pi = X$.

Buildings Let $\mathbb{K}$ be a non-Archimedean local skew field endowed with a valuation $v$. An $\mathcal{O}$-lattice of $\mathbb{K}^n$ is an $\mathcal{O}$-submodule which generates $\mathbb{K}^n$ as a $\mathbb{K}$ vector space. Such a lattice can be written as $\mathcal{O}e_1 + \cdots + \mathcal{O}e_n$ for a basis $(e_1, \ldots, e_n)$ of $\mathbb{K}^n$. Since for any $a \in \mathbb{K}^*$ and any lattice $L$, the module $aL$ is also a lattice, we can define the equivalence relation of lattices modulo homothety. We denote by $[L]$ the class of a lattice $L$.

The Bruhat-Tits building of $\text{PSL}_n(\mathbb{K})$ is a simplicial complex of dimension $n - 1$ denoted by $\hat{X}$ whose 1-skeleton (denoted by $X$) is described as follows. The vertices are the classes of $\mathcal{O}$-lattices modulo homothety. Two vertices $x_1$ and $x_2$ are linked by an edge if there exists representatives $L_1$ of $x_1$ and $L_2$ of $x_2$ such that:

$$pL_1 \subset L_2 \subset L_1.$$ 

Example 2.5. One can show that the building of $\text{PSL}_2(\mathbb{Q}_p)$ is a $(p + 1)$-regular tree. Figure 3a gives a representation of the building when $p = 2$.

(a) The building has two $\text{SL}_2(\mathbb{Q}_2)$-orbits

(b) Representation of one apartment

Figure 3: The building of $\text{PSL}_2(\mathbb{Q}_2)$
The usual action of $\text{GL}_n(\mathbb{K})$ on $\mathbb{K}^n$ induces an action of $\text{PGL}_n(\mathbb{K})$ on $\mathcal{X}$ by isometry. Since $\text{GL}_n(\mathbb{K})$ acts transitively on the bases, the action of $\text{PGL}_n(\mathbb{K})$ on the vertices of $\mathcal{X}$ is also transitive.

If $L = \bigoplus_i \mathcal{O} e_i$ is a lattice we define its *type* to be $\nu(\det(e_1, \ldots, e_n))$. Since:

$$\forall a \in \mathbb{K}^* \nu(\det(ae_1, \ldots, ae_n)) = \nu(\det(e_1, \ldots, e_n)) \mod n,$$

one can define the *type of a vertex* $x$ in $\mathcal{X}$ to be the value modulo $n$ of the type of one of its representatives. We denote by $\tau(x)$ the type of $x$.

If $L'$ is a second lattice, we can choose our basis $e_1, \ldots, e_n$ for $L$ in such a way that $L'$ admits a basis of the form $a_1 e_1, \ldots, a_n e_n$ for some $a_i \in \mathbb{K}^*$. The scalars $a_i$ can be taken to be powers of $\pi$. The incidence relation defined above implies that if the classes of $L$ and $L'$ are linked by an edge in $\mathcal{X}$, then they have different types.

**Remark 2.6.** Remark that if $L = \bigoplus_i \mathcal{O} e_i$ and

$$L' = \mathcal{O} \pi e_1 \oplus \cdots \oplus \mathcal{O} \pi e_j \oplus e_{j+1} \oplus \cdots \oplus e_n,$$

then $\tau([L]) = \tau([L']) + j \mod n$.

The action of $\text{SL}_n(\mathbb{K})$ on $\mathcal{X}$ preserves the determinant and is transitive on the pairs of vertices of the same type. So there are exactly $n$ orbits under the action of $\text{SL}_n(\mathbb{K})$ (see Figure 3a and Figure 4 for examples).

**Apartments**

If $e$ is a basis of $\mathbb{K}^n$ then the sub-complex $\mathcal{A}$ induced by the set of vertices $\{ \bigoplus_{i=1}^n \mathcal{O} \pi^{k_i} e_i \mid k_i \in \mathbb{Z} \}$ is isometric to a $(n-1)$-dimensional Euclidean space tiled by regular $(n-1)$-simplices. We call such sub-complexes *apartments*. For example an apartment in the building of $\text{PSL}_2(\mathbb{Q}_2)$ is isometric to $\mathbb{R}^1$ tiled with segments of length 1 (see Figure 3b), whereas for $\text{PSL}_3(\mathbb{Q}_2)$ the apartment are isometric to $\mathbb{R}^2$ and tiled with triangles (see Figure 4).

![Figure 4: Apartment in the building of $\text{PSL}_3(\mathbb{Q}_2)$](image)

For any two points in $\hat{\mathcal{X}}$ there exists an apartment containing them. If $x, y \in \hat{\mathcal{X}}$ let $\mathcal{A}$ be an apartment containing $x$ and $y$ and define $d_{\hat{\mathcal{X}}}(x, y)$ to be equal to the euclidean distance $d_{\mathcal{A}}(x, y)$. This definition does not depend on the choice
of apartment $\mathcal{A}$ and thus endows $\hat{\mathcal{X}}$ with a well defined distance. Moreover, this distance verifies the negative curvature inequality: for all $x, y, z \in \hat{\mathcal{X}}$ and $t \in [0, 1]$

$$d^2_{\hat{\mathcal{X}}}(z, tx + (1 - t)y) \leq td^2_{\hat{\mathcal{X}}}(z, x) + (1 - t)d^2_{\hat{\mathcal{X}}}(z, y) - t(1 - t)d^2_{\hat{\mathcal{X}}}(x, y).$$

Denote by $d_{\hat{\mathcal{X}}}$ the distance on the 1-skeleton $\hat{\mathcal{X}}$ assigning length 1 to an edge. Then $d_{\hat{\mathcal{X}}}(x, y)$ is greater than $d_{\hat{\mathcal{X}}}(x, y)$ for all vertices $x$ and $y$ in $\hat{\mathcal{X}}$.

**Contractibility** Using the above inequality one can show that the building is contractible (see [AB18] for more details). We can actually show that convex sets in $\hat{\mathcal{X}}$ are themselves contractible.

**Claim 2.7.** Let $r > 0$. Any convex set in $\hat{\mathcal{X}}$ is contractible.

**Proof.** Let $r > 0$ and $\mathcal{C}$ a convex set in $\hat{\mathcal{X}}$ and endow it with the distance induced by $d_{\hat{\mathcal{X}}}$. Take $x_0 \in \mathcal{C}$ and define,

$$\mathcal{H} : \begin{cases} [0, 1] \times \mathcal{C} & \to \mathcal{C}, \\ (t, x) & \mapsto tx + (1 - t)x_0. \end{cases}$$

Since $\mathcal{C}$ is convex, the map $\mathcal{H}$ is well-defined. Moreover $\mathcal{H}(0, \cdot) = \text{id}_{\mathcal{C}}$ and $\mathcal{H}(1, x) = x_0$ for all $x \in \mathcal{C}$. Let us show that $\mathcal{H}$ is continuous. Take $x, x' \in \mathcal{C}$ and $t, t' \in [0, 1]$ and let $z = t'x' + (1 - t')x_0$. By eq. (1)

$$d^2_{\hat{\mathcal{X}}}(z, tx + (1 - t)x_0) \leq td^2_{\hat{\mathcal{X}}}(z, x) + (1 - t)d^2_{\hat{\mathcal{X}}}(z, x_0) - t(1 - t)d^2_{\hat{\mathcal{X}}}(x, x_0).$$

But if $\mathcal{A}$ is a an apartment containing $z$ and $x_0$, then by property of the Euclidean distance $d_{\mathcal{A}}$

$$d_{\hat{\mathcal{X}}}(z, x_0) = d_{\mathcal{A}}(t'x' + (1 - t')x_0, x_0) = t'd_{\mathcal{A}}(x', x_0) = t'd_{\hat{\mathcal{X}}}(x', x_0),$$

which tends to $td_{\hat{\mathcal{X}}}(x, x_0)$ as $(t', x')$ tends to $(t, x)$. Similarly

$$d_{\hat{\mathcal{X}}}(z, x) \leq d_{\hat{\mathcal{X}}}(z, x') + d_{\hat{\mathcal{X}}}(x', x) = d_{\hat{\mathcal{X}}}(t'x' + (1 - t')x_0, x') + d_{\hat{\mathcal{X}}}(x', x),$$

which converges to $(1 - t)d_{\hat{\mathcal{X}}}(x, x_0) + d_{\hat{\mathcal{X}}}(x', x)$ as $(t', x')$ tends to $(t, x)$. Thus the right term of eq. (2) converges to 0 as $(t', x')$ tends to $(t, x)$. Hence the continuity of $\mathcal{H}$ and the contractibility of $\mathcal{C}$.

\[ \square \]

### 2.2 Large scale simple connectedness

For a graph $\mathcal{G}$ and $k \in \mathbb{N}$, we define a 2-complex, noted $P_k(\mathcal{G})$, such that:

- Its 1-skeleton is given by $\mathcal{G}$;
- Its 2-skeleton is composed of $m$-gons (for $m \in [0, k]$) defined by the simple loops of length $m$ in $\mathcal{G}$ (up to cyclic permutations).
**Definition 2.8**

We say that $\mathcal{G}$ is $k$-simply connected or simply connected at scale $k$ if $P_k(\mathcal{G})$ is simply connected.

**Example 2.9.** Let $G$ be a finitely generated group and $T$ a finite symmetric generating set. The Cayley graph $(G, T)$ is simply connected at scale $k$ if and only if $G$ has a presentation $\langle T, R \rangle$ with relations of length at most $k$.

**Example 2.10.** Let $n \geq 2$. The Bruhat-Tits building of $\text{PSL}_n(\mathbb{K})$ is simply connected at scale 3.

**Remark 2.11.** If $k \leq k'$, then every $k$-simply connected graph is $k'$-simply connected.

The following proposition allows us to restrict the study of the LG-rigidity of a graph $\mathcal{G}$ to some smaller class of graphs.

**Proposition 2.12 (de la Salle, Tessera, [dlST16, Proposition 1.5])**

Let $k \in \mathbb{N}$ and $\mathcal{G}$ be a $k$-simply connected graph, with cocompact isometry group. Then $\mathcal{G}$ is LG-rigid if and only if there exists $R$ such that every $k$-simply connected graph which is $R$-locally $\mathcal{G}$ is isometric to $\mathcal{G}$.

To apply this result to our proof we will need to show that the studied graph $X$ is simply connected. The following proposition shows that being simply connected is invariant under quasi-isometry.

**Proposition 2.13 (de la Salle, Tessera, [dlST16, Theorem 2.2])**

Let $k \in \mathbb{N}^*$ and let $\mathcal{G}$ be a $k$-simply connected graph. If $\mathcal{H}$ is quasi-isometric to $\mathcal{G}$, then there exists $k' \in \mathbb{N}^*$ such that $\mathcal{H}$ is simply connected at scale $k'$.

Before moving to the next section, let us mention a consequence of Proposition 2.12. Indeed, this result allows us to look at the LG-rigidity notion with a topological point of view. Let’s denote $\mathfrak{G}_k$ the set of isometry classes of locally finite $k$-simply connected graphs. We can define a distance on this set by:

$$d_{\mathfrak{G}_k}(X, Y) := \inf \left\{ 2^{-R} : X \text{ and } Y \text{ are } R\text{-close} \right\},$$

which endows $\mathfrak{G}_k$ with a topology. Proposition 2.12 implies that a graph is LG-rigid if and only if its isometry class in $\mathfrak{G}_k$ is isolated for this topology.

### 2.3 Extension of isometries

In order to build the “hybrid” graph mentioned above, we will need some result to extend globally our local definition of edges. We recall here the result of de la Salle and Tessera [dlST19, Lemma 4.1] that will serve our purpose.
Proposition 2.14 (*de la Salle, Tessera*)

Let $\mathcal{G}$ be a graph with cocompact isometry group. Given some $r_1 \geq 0$, there exists $r_2 > 0$ such that: for every $g \in \mathcal{G}$, the restriction to $B_\mathcal{G}(g, r_1)$ of an isometry $f : B_\mathcal{G}(g, r_2) \to \mathcal{G}$ coincides with the restriction of an element of Isom$(\mathcal{G})$.

It is however not necessarily true that $f$ coincides on the whole $B(g, r_2)$ with an isometry of $\mathcal{G}$. Indeed, truncating the entire graph to some ball might allow some kind of flexibility near the boundary of the ball (see Example 2.15 and Figure 5). Hence, in order to coincide with a global isometry we need to restrict the local isometry $f$ to a smaller ball which does not contain the flexible area.

Example 2.15. Let $\mathcal{G}$ be the Cayley graph of $\mathbb{Z}^2$ endowed with its usual generating part. We consider in Figure 5 an isometry $f$ defined on $B((0,0), 1)$ such that $f$ fixes $(0,0), (-1,0)$ and $(0,-1)$ (represented by the blue vertices) and exchange $(1,0)$ with $(0,1)$ (the orange and brown vertices). Then $f$ is an isometry from $B((0,0), 1)$ to $B((0,0), 1)$, but can not coincide with a global isometry of $\mathcal{G}$ on that ball. Indeed, if such a global isometry existed, then it should send the vertex $(-1,1)$ (represented by the light brown vertex on the left part of the figure) at distance 1 from both $f(-1,0) = (-1,0)$ and $f(0,1) = (1,0)$. Which is impossible since the only point at distance 1 from $(1,0)$ and $(-1,0)$ is $(0,0)$ and it is already the image of $(0,0)$.

![Figure 5: Local isometry that can not coincide with a global isometry on its entire domain of definition](image)

2.4 Preliminary results on $X$

Lemma 2.16

If $X$ verifies the hypothesis of Theorem 1.18, then $\text{PSL}_n(\mathbb{K})$ is included in $\rho(\text{Isom}(X))$. Moreover, if $q(X)$ contains a vertex of a certain type $i$, then $q(X)$ contains all the vertices of type $i$.

Proof. Since $\rho(\text{Isom}(X))$ is of finite index in the isometry group of the building $X$, the same goes for its normal core $\cap_{g \in \text{Isom}(X)} g\rho(\text{Isom}(X)) g^{-1}$. Then, by simplicity of $\text{PSL}_n(\mathbb{K})$, the normal core of $\rho(\text{Isom}(X))$ contains $\text{PSL}_n(\mathbb{K})$. Hence the result.

Then, the second part of the lemma follows from the equivariance of $q$ and the transitivity of $\text{PSL}_n(\mathbb{K})$ on vertices of the same type. $\square$
3 Tracking vertices through their prints

Without loss of generality, we can assume that \( \text{im}(q) \) contains type 0 vertices, that is to say \( \tau^{-1}(0) \subset \text{im}(q) \). Moreover, using Proposition 2.13 we obtain that \( X \) is simply connected at some scale \( k > 0 \).

*  
The aim of the next two sections is to prove Theorem 1.18 for \( n \geq 4 \). For the sake of clarity we recapitulate here the needed assumptions for the proof.

**Hypothesis (H)**  
1. Let \( X \) be a \( k \)-simply-connected transitive graph;  
2. Let \( Y \) be a graph \( R \)-locally \( X \) and \( k \)-simply connected;  
3. Let \( n \geq 4 \) and \( K \) a non-Archimedean local skew field of characteristic zero. Denote by \( \mathcal{X} \) the Bruhat-Tits building of \( \text{PSL}_n(K) \);  
4. Let \( \rho : \text{Isom}(X) \to \text{Isom}(X) \) be an injective homomorphism and \( q : X \to \mathcal{X} \) an \( \text{Isom}(X) \)-equivariant injective quasi-isometry;  
5. Assume that \( \rho(\text{Isom}(X)) \) is of finite index in \( \text{Isom}(\mathcal{X}) \) and that \( q(X) \) contains \( \tau^{-1}(0) \).

3 TRACKING VERTICES THROUGH THEIR PRINTS

This section is dedicated to the definition of a graph locally the same as \( \mathcal{X} \) which we will call \( \mathcal{Y} \). Before moving to the detailed definition let us explain the idea of the construction. Recall that the vertices of \( \mathcal{X} \) are partitioned into different types (see Section 2.1) denoted by integers in \( \{0, \ldots, n-1\} \). By Lemma 2.16, if \( q(X) \) contains a vertex of a certain type then it contains all the vertices of that type. Denote by \( T \) the set of types that are not contained in \( q(X) \), namely \( T = \{0, \ldots, n-1\}\setminus \tau(q(X)) \). We have the following partition

\[
\mathcal{X} = q(X) \cup \left( \sqcup_{i \in T} \tau^{-1}(i) \right).
\]  

**Example 3.1.** Take \( K = \mathbb{Q}_2 \) and assume that \( \text{im}(q) \) is composed only of type zero vertices.  
When \( n = 2 \) we have \( T = \{1\} \) and the building is represented in Figure 3a. The partition in eq. (3) corresponds to the partition of vertices in two different colors.  
When \( n = 3 \), we get \( T = \{1, 2\} \). An apartment of \( \mathcal{X} \) is represented in Figure 4 and the partition of this part of \( \mathcal{X} \) corresponds to the partition in three different colors.

**Example 3.2.** Let \( n = 4 \) and \( K = \mathbb{Q}_2 \) and assume that \( \text{im}(q) \) contains type zero and type 2 vertices. Then \( T = \{1, 3\} \). We will not try to represent \( \mathcal{X} \) or an apartment but recall that it is tiled by tetrahedrons. The partition is illustrated on a tetrahedron in Figure 6, where \( \text{im}(q) \) corresponds to the two blue vertices.
3 Tracking vertices through their prints

The idea of the construction of $Y$ is to take the vertices of $Y$ and add to them vertices of the missing types, i.e., vertices with type in $T$ (see Figure 10 for an example). But we want to build this vertices only with informations encoded in $V(Y)$. That is why we introduce the local characterization of a vertex in the building (see Section 3.1). Then, using a well chosen set of isometries from $Y$ to $X$, we transfer this print notion to $Y$, each print in $Y$ corresponding to a vertex of a missing type.

3.1 Prints in a building

In this section we show that a vertex in $X$ can be determined by a part of its 1-neighbourhood. More precisely, we prove that a vertex in the building is entirely determined by the vertices in its 1-neighbourhood having type zero.

**Definition 3.3** Let $x$ be a vertex of $X$. We define the print of $x$, denoted by $\mathcal{P}(x)$, to be the intersection of the 1-neighbourhood of $x$ with the vertices of type zero, viz. $\mathcal{P}(x) := B_X(x, 1) \cap \tau^{-1}(0)$.

**Remark 3.4.** We choose to define print as a set of vertices of type zero because (in order to simplify notations and proofs) we assumed from the beginning that $\tau^{-1}(0)$ was contained in $\text{im}(q)$. But we could have taken any other type.

**Example 3.5.** Figure 7 represents a ball of radius 1 in two different cases. The case when $n = 2$ and $|O/\pi O| = 2$ (for example when $K = Q_2$) is represented on the left figure. The case when $K = Q_2$ and $n = 3$ is represented on the right figure. In each case, the print of $x$ corresponds to the set of blue vertices.

The following result proves that a vertex in $X$ is uniquely determined by its print.

**Proposition 3.6** Let $x_1, x_2 \in X$. If $\mathcal{P}(x_1) = \mathcal{P}(x_2)$, then $x_1 = x_2$.

Before showing the above property, let us recall (and prove) a useful fact concerning the choice of representative of a vertex.
3 Tracking vertices through their prints

\[ \mathcal{P}(x) = \{x_1, x_2, x_3\} \]

\[ \mathcal{B}(x, 1) \text{ for } n = 2 = p \quad \text{and} \quad \mathcal{B}(x, 1) \text{ for } p = 2 \text{ and } n = 3 \]

Figure 7: Prints and 1-neighbourhood of a vertex in \( X \)

**Claim 3.7.** For any vertex in \( X \), we can always find a representative \( \oplus_i \mathcal{O} \pi^{k_i} e_i \) of the vertex such that
\[
\begin{align*}
\forall i \in \{1, \ldots, n\} & \quad k_i \geq 0, \\
\exists i_0 \in \{1, \ldots, n\} & \quad k_{i_0} = 0.
\end{align*}
\]

*Proof of the claim.* Indeed, let \( x \in X \) and let \( (l_1, \ldots, l_n) \) be a representative of \( x \) and let \( i_0 \) be such that \( l_{i_0} = \min_i l_i \), then
\[
\left[ \oplus_{i=1}^n \mathcal{O} \pi^{l_i} e_i \right] = \pi^{-l_{i_0}} \left[ \oplus_{i=1}^n \mathcal{O} \pi^{l_{i_0} - l_{i_0}} e_i \right] = \left[ \oplus_{i=1}^n \mathcal{O} \pi^{l_{i_0}} e_i \right].
\]
Thus \( (l_1 - l_{i_0}, \ldots, l_1 - l_{i_0}) \) is a representative of \( x \) and verifies eq. (4).

Now, let us prove that the print determines the vertex.

*Proof of Proposition 3.6.* Let \( x_1, x_2 \in X \) such that \( \mathcal{P}(x_1) = \mathcal{P}(x_2) \).

First remark that if \( \tau(x_1) = 0 \) then \( \mathcal{P}(x_1) = \{x_1\} \) which implies that \( \mathcal{P}(x_2) = \mathcal{P}(x_1) = \{x_1\} \). But then \( x_2 \) has only one neighbour of type 0, which is only possible if \( \tau(x_2) = 0 \). Thus \( (x_2) = \mathcal{P}(x_2) = \{x_1\} \) and so \( x_1 = x_2 \).

Now assume that \( \tau(x_1) \neq 0 \) and take \( A \) to be an apartment containing both \( x_1 \) and \( x_2 \). Define \( \mathcal{P} := \mathcal{P}(x) \cap A \) and let \( e \) be a basis such that
\[
A = \left\{ \oplus_{i=1}^n \mathcal{O} \pi^{k_i} e_i \mid k_i \in \mathbb{Z} \right\} \text{ and } x_1 = (0, \ldots, 0).
\]

By Claim 3.7, we can choose a representative \( (k_1, \ldots, k_n) \) of \( x_2 \) such that \( k_i \geq 0 \) for all \( i \) and there exists \( j \in \{1, \ldots, n\} \) such that \( k_j = 0 \). Now define the sequence \( i_1, \ldots, i_n \) of indices such that \( k_{i_n} \geq \cdots \geq k_{i_1} = 0 \) and let
\[
l_{i_1} = \cdots = l_{i_{\tau(x)}} = 1 \quad l_{i_{\tau(x)+1}} = \cdots = l_{i_n} = 0.
\]

Then by remark 2.6 the vertex \( z = (l_1, \ldots, l_n) \) has type 0. Moreover it is at distance 1 from \( x_1 \), so \( z \) belongs to \( \mathcal{P} \). But if \( k_{i_n} > 0 \), then \( d(z, x_2) > 1 \) thus \( z \) can not belong to \( \mathcal{P}(x_2) \). Hence \( k_{i_1} \leq 0 \), that is to say \( k_i = 0 \) for all \( i \) and thus \( x_2 = x_1 \). \( \Box \)
This proves that a vertex in $X$ is uniquely determined by its print. Thus, we can introduce the following definition without ambiguity.

**Definition 3.8**

Let $x$ to be a vertex in $X$. We say that $x$ is the *source* of $P(x)$.

In order to prove Theorem 1.18, we will need to know how prints behave under the action of $\text{PSL}_n(K)$. So let $x \in X$ and let $\alpha \in \text{PSL}_n(K)$. Since $\alpha$ is an isometry, we get

$$\alpha(P(x)) = \alpha(B(x, 1) \cap \tau^{-1}(0)) = \alpha(B(x, 1)) \cap \alpha\tau^{-1}(0) = B(\alpha(x), 1) \cap \tau^{-1}(0).$$

We deduce the following lemma.

**Lemma 3.9**

Let $x \in X$. If $\alpha$ belongs to $\text{PSL}_n(K)$, then $\alpha(P(x)) = P(\alpha(x))$.

### 3.2 Atlas of local isometries

To build our graph locally the same as $X$, we need to restrict ourselves to a particular set of local isometries from $Y$ to $X$. More precisely, if $y_1$ and $y_2$ are close in $Y$ and $f_1$ (resp. $f_2$) is an isometry from $B_Y(y_1, R)$ (resp. $B_Y(y_2, R)$) to $X$, we want the transition map $f_2f_1^{-1}$ to coincide with an element in $\rho^{-1}\text{PSL}_n(K)$ on a small ball. This is what we formalize here and schematize in Figure 8.

In order to avoid any ambiguity regarding the notion of center of a ball, let us precise our definition of ball in a graph. What we mean when we talk of “a ball of radius $R$” is actually a pointed ball of radius $R$ that is to say, a couple $(B, y)$ such that $y$ is a vertex in $Y$ and $B = B_Y(y, R)$. We will abuse notation by denoting such a pointed ball $B_Y(y, R)$ (instead of $(B_Y(y, R), y)$). This way, the center of a ball is always well defined.

**Definition 3.10**

Let $\mathcal{A}$ be a set of isometries from balls of radius $R$ in $Y$ to $X$. We say that $\mathcal{A}$ is an atlas of local isometries from $Y$ to $X$ if the map that associates to each isometry in $\mathcal{A}$ the center of its ball of definition is a bijection from $\mathcal{A}$ to $Y$. That is to say, we can write $\mathcal{A} := \{f_y : B_Y(y, R) \to X \mid y \in Y\}$, where the map that associates $f_y$ to $y$ is bijective.

We say that $f_y$ is the isometry associated to $y$ in $\mathcal{A}$.

Let $H_0 := \rho^{-1}\text{PSL}_n(K)$. Now, we show that we can construct an atlas of local isometries from $Y$ to $X$ such that the transition maps between two isometries defined on balls with neighbouring centers coincide with elements of $H_0$.

We will note a path between two vertices $v_1$ and $v_2$ as a sequence $(v_1, \ldots, v_l)$ of adjacent vertices.
Lemma 3.11
Let \( r_A > 0 \) and let \( H_0 := \rho^{-1} \text{PSL}_n(\mathbb{K}) \). For \( R \) large enough, if \( Y \) is \( R \)-locally \( X \), then there exists an atlas \( \mathcal{A} \) such that for any two neighbours \( y \) and \( z \) in \( Y \)
\[
\exists a \in H_0 \quad f_y f_z^{-1} |_{\mathcal{B}(f_z(z), r_A)} = a |_{\mathcal{B}(f_z(z), r_A)}.
\]

Before proving it, let us schematize the framework of this lemma. In Figure 8 we represent two isometries \( f_y \) and \( f_z \) with \( z \) neighbour to \( y \). The larger discs correspond to balls of radius \( R \) and the smaller ones to balls of radius \( r_A \). The map \( f_y f_z^{-1} \) restricted to \( \mathcal{B}(f_z(z), r_A) \) takes \( f_z(z) \) to \( f_y(z) \) which is a neighbour of \( f_y(y) \) and coincides on this ball with an element in \( H_0 \).

![Figure 8: Composition of isometries with neighbouring centers](image)

Let us discuss the idea of the proof. First, for two neighbours \( y \) and \( z \) we use Proposition 2.14 to prove that \( f_y f_z^{-1} \) coincides on a small ball with an element \( a \) in \( \text{Isom}(X) \). This isometry corresponds to the "default" of belonging to \( H_0 \) we want to correct. Hence, we consider in our atlas the new isometry defined on \( \mathcal{B}(z, R) \) by \( a f_z \).

Finally, we extend this construction along paths in \( Y \) and prove that the wanted property for \( \mathcal{A} \) does not depend on the choice of path.

Proof. Let \( r_A > 0 \) and let \( H_0 := \rho^{-1} \text{PSL}_n(\mathbb{K}) \). Now, let \( y \in Y \) and \( f_y \) be an isometry from \( \mathcal{B}(y, R) \) to \( X \). Let \( z \) be a neighbour of \( y \) in \( Y \) and \( f_z \) be an isometry from \( \mathcal{B}(z, R) \) to \( X \). Then the map
\[
f_y f_z^{-1} : \mathcal{B}_X(\hat{f}_z(z), R - 1) \to \mathcal{B}_X(f_y(z), R - 1)
\]
is a well defined local-isometry of \( X \). By Proposition 2.14 if \( R \) is large enough, there exists \( a \) in \( \text{Isom}(X) \) such that \( f_y f_z^{-1} \) coincides with \( a \) on \( \mathcal{B}_X(\hat{f}_z(z), r_A + k) \), where we recall that \( k \) refers to the scale at which \( Y \) is simply connected. We will see below why we need to consider such a radius.
Now let $f_z := \alpha f_z$. By definition we have

$$f_z : \begin{cases} B_Y(z, R) & \rightarrow B_X(f_y(z), R), \\ z & \mapsto \alpha f_z(z) = f_y(z), \end{cases}$$

thus the transition map $f_y f_z^{-1}$ is well defined on $B_X(f_z(z), R - 1)$. Moreover, by choice of $f_z$ we get that $f_y f_z^{-1} z$ restricted to $B(f_y(z), r_A + k)$ coincides with the identity and thus belongs to $H_0$. Extending this construction along paths in $Y$ we get an atlas $\mathcal{A}$ of local isometries from $Y$ to $X$.

Now if $y \in Y$ and $f_y$ is the associated isometry in $\mathcal{A}$, we want to show that (up to a multiplication by an element in $\text{PSL}_n(\mathbb{K})$) this isometry does not depend on the choice of path. So let $y \in Y$ and $(y_0 = y, y_1, \ldots, y_l = y)$ be a loop of length $l$. Take $f_0$ to be an isometry from $B_Y(y_0, R)$ to $X$ and using the process detailed above, build a sequence of isometries $f_1, \ldots, f_l$ such that $f_i$ is defined on $B_Y(y_i, R)$ and

$$\forall i \in \{1, \ldots, l\} \exists a_i \in H_0 \mid (f_{i-1} f_i^{-1})_{|B(f_i(y_{i-1}), r_A + k)} = a_i |_{B(f_i(y_{i-1}), r_A + k)}.$$ We have to prove that the restrictions to $B(y_0, r_A)$ of $f_0$ and $f_l$ are equal up to a multiplication by an element in $H_0$. Since $Y$ is simply connected at scale $k$, we only have to prove this for loops of length smaller than $k$. Hence, we assume that $l \leq k$.

First, remark that for all $i \in \{0, \ldots, l - 1\}$

$$\begin{cases} f_{i-1} f_i^{-1} : B_X(f_i(y_i), r_A + k) & \rightarrow B_X(f_{i-1}(y_{i-1}), r_A + k), \\ f_i f_{i-1}^{-1} : B_X(f_{i-1}(y_{i-1}), r_A + k) & \rightarrow B_X(f_i(y_{i-1}), r_A + k). \end{cases}$$

Now since $y_1$ and $y_{i+1}$ are at distance 1, the ball $B_X(f_i(y_{i+1}), r_A + k - 1)$ is included in $B_X(f_i(y_{i-1}), r_A + k)$. Hence the map $(f_{i-1} f_i^{-1}) (f_i f_{i-1}^{-1})$ is well defined and coincides with $a_i a_{i+1}$ on $B_X(f_{i-1}(y_{i+1}), r_A + k - 1)$. By induction we get that for all $x$ in $B_X(f_{i+1}(y_{i+1}), r_A + k - l + 1)$

$$f_0 f_{i-1}^{-1}(x) = (f_0 f_{i-1}^{-1}) \cdots (f_{i-1} f_{i-2}^{-1}) (x) = a_1 \cdots a_i(x).$$

Since $\prod_{i=1}^{l} a_i$ belongs to $H_0$ and $l$ is smaller than $k$, it implies that $f_0$ is equal to $f_l$ on $B_Y(y_0, r_A)$ up to multiplication by an element in $H_0$.

The atlas is defined such that a transition map between two isometries defined on balls with neighbouring centers belongs to $H_0$. But in fact, this property is also true when the centers are at a slightly bigger distance.

**Lemma 3.12**

Let $r > 0$ and $\mathcal{A}$ be an atlas verifying the conditions of Lemma 3.11 with $r_A > 3r$. Let $y$ and $z$ in $Y$ be at distance less than $2r$ and $f_y, f_z$ the associated isometries in $\mathcal{A}$. Then

$$\exists a \in H_0 \mid (f_y f_z^{-1})_{|B_Y(z, r)} = a |_{B_Y(z, r)}. \quad (6)$$
3 Tracking vertices through their prints

Proof. Let \( r > 0 \) and assume \( r_A > 3r \). Let \( y, z \in Y \) be at distance \( l \leq 2r \) and let \( f_y, f_z \) be two elements of \( \mathfrak{A} \) such that

\[
f_y : B_Y(y, R) \to X \quad f_z : B_Y(z, R) \to X.
\]

Take \( (y_0 = y, y_1, \ldots, y_l = z) \) to be a geodesic between \( y \) and \( z \), and for all \( i \in \{0, \ldots, l \} \), let \( f_i \in \mathfrak{A} \) be the isometry associated to \( y_i \). Remark that by definition of an atlas, it implies \( f_0 = f_y \) and \( f_1 = f_z \) and

\[
\forall i \in \{0, \ldots, 1 - 1 \} \quad \exists a_i \in H_0 \quad (f_i f_{i+1})^{-1} |_{B(f_i(y_{i+1}), r_A)} = a_i |_{B(f_i(y_{i+1}), r_A)}.
\]

Now, if \( r_A > 3r \) and \( l \leq 2r \), then \( B_Y(z, r) \) is contained in \( B_Y(y, r_A) \). Hence the composition of transition maps \((f_0 f_1^{-1}) \cdots (f_{l-1} f_1^{-1})\) is well defined on \( B_Y(f_1(y_1), r_A - 1) \) and verifies on that ball

\[
f_0 f_1^{-1} = (f_0 f_1^{-1}) \cdots (f_{l-1} f_1^{-1}) = a_0 \cdots a_{l-1}. \quad (7)
\]

Hence the result. \( \square \)

3.3 Prints in \( Y \)

Using the atlas built above, we can now transfer this print notion to the graph \( Y \). Let \( r_p > 0 \) and assume that \( Y \) is endowed with an atlas of isometries \( \mathfrak{A} \) as given by Lemma 3.11 with \( r_A > 3r_p \). Hence, we have

\[
R > r_A > 3r_p > r_p.
\]

Definition 3.13

Let \( P \) be a set of vertices in \( Y \). We say that \( P \) is a print if there exists \( y \in Y \) and \( f \in \mathfrak{A} \) an isometry from \( B_Y(y, R) \) to \( X \) such that

- The set \( P \) is contained in \( B_Y(y, r_p) \);
- There exists \( x \in X \setminus \text{im}(q) \) such that \( \mathcal{P}(x) = qf(P) \).

Remark 3.14. Note that in the definition above we ask that \( x \) does not belong to \( \text{im}(q) \). The definition would also make sense if \( x \) belonged to \( \text{im}(q) \) but the purpose of these prints is to reconstruct the "missing" vertices, namely vertices that are not in the image of \( q \). Thus to simplify formalism in the next pages, we chose to restrict now the definition to prints of vertices in \( X \setminus \text{im}(q) \).

Example 3.15. If \( n = 3 \) and \( p = 2 \) there are exactly 3 types of vertices, each represented in Figure 9 by a different color. The 1-neighborhood of a vertex \( x \) in \( X \) is then composed of fourteen vertices, represented on the right side of the aforementioned figure (where \( x \) is the brown vertex at the center). If \( x \in X \setminus \text{im}(q) \) then seven of these fourteen vertices are in \( \text{im}(q) \) (the blue vertices). On the left side of the figure is represented \( P \) (the black dots) inside \( B(y, r_p) \) (the darker disc). The set \( qf(P) \) is exactly the set of blue vertices. Hence \( P \) is a print.
3 Tracking vertices through their prints

\[ \gamma \rightarrow qf \rightarrow \chi \]

**Figure 9:** Definition of a print in \( Y \)

For now, let’s say that \( P \) verifying the definition above is a print *associated to* \( y \) and \( f \). We are going to show that this definition depends neither on \( y \) nor \( f \).

**Lemma 3.16**

Let \( y_1, y_2 \in Y \) and \( f_1, f_2 \) be the associated isometries in \( A \). Let \( P \) be a print associated to \( y_1 \) and \( f_1 \).

If \( P \subset B(y_2, r_P) \) then \( P \) is a print associated to \( y_2 \) and \( f_2 \).

**Proof.** First, remark that since \( P \subset B(y_2, r_P) \cap B(y_1, r_P) \), then taking any \( y \) in \( P \) we get

\[ d_Y(y_1, y_2) \leq d_Y(y_1, y) + d_Y(y, y_2) \leq 2r_P. \]

Applying Lemma 3.12 with \( r = r_P \), we get that there exists \( a \in H_0 \) such that

\[ (f_1f_2^{-1})|_{B_X(f_2(y_2), r_P)} = a|_{B_X(f_1(y_2), r_P)}. \]

Now let \( x \in X \) be such that \( \mathcal{P}(x) = qf_1(P) \). Using the equivariance of \( q \) and Lemma 3.9, we get

\[ qf_2(P) = \rho(a)^{-1}qf_1(P) = \rho(a)^{-1}\mathcal{P}(x) = \mathcal{P}(\rho(a)^{-1}(x)). \]

Hence \( P \) is a print associated to \( y_2 \) and \( f_2 \). \( \square \)

This last lemma proves that being a print does not depend on the choice of local isometry.

**Remark 3.17.** In the above proof \( \rho(a)^{-1}(x) \) has same type as \( x \) since \( \rho(a) \) is type preserving. Thus, once we have taken our atlas in \( \text{PSL}_n(\mathbb{K}) \), the type of the source of \( qf(P) \) does not depend on the choice of local isometry \( f \).
3 Tracking vertices through their prints

3.4 Definition of \( Y \): a building’s replica

The following property defines the graph \( Y \) we will demonstrate to be locally the same as \( X \).

**Proposition 3.18**

Let \( r_p > 0 \) and \( \mathfrak{A} \) be the atlas given by Lemma 3.11 for \( r_A > 3r_p \). If \( R \) is large enough, then the following graph is well defined.

Let \( Y \) be the graph whose vertices are given by

\[
V(Y) := V(X) \cup \{ P : \exists y \in X \setminus \Im(q), \ P(x) = P \},
\]

and edges are given by:

- If \( y_1, y_2 \in V(Y) \), then \((y_1, y_2)\) is an edge if there exists \( z \) in \( Y \) and \( f \in \mathfrak{A} \) defined on \( B_Y(z, R) \) such that \( y_1, y_2 \in B(z, r_p) \) and \( d_X(qf(y_1), qf(y_2)) = 1 \).
- If \( y \in V(Y) \) and \( P \) is a print, then \((y, P)\) is an edge if there exists \( z \) in \( Y \) and \( f \in \mathfrak{A} \) defined on \( B_Y(z, R) \) containing \( y \) and \( P \) and such that \( qf(y) \) is at distance 1 from the source of \( qf(P) \).
- If \( P_1 \) and \( P_2 \) are two prints, then \((P_1, P_2)\) is an edge if there exists \( z \) in \( Y \) and \( f \in \mathfrak{A} \) defined on \( B_Y(z, R) \) such that \( P_1, P_2 \subset B_Y(z, r_p) \) and such that the source of \( qf(P_1) \) is at distance 1 from the source of \( qf(P_2) \).

Before looking at the proof of this property, let us sketch some part of this graph.

**Example 3.19.** If \( n = 4 \) then \( X \) is composed of vertices of type 0, 1, 2 and 3. Assume that \( q(X) \) is composed of vertices of type 0 and 2, then \( T = \{1, 3\} \) and we saw the corresponding partition of \( X \) in Example 3.2 and Figure 6. The appearance of the corresponding \( V(Y) \) is represented in Figure 10.

![Figure 10: Schematic view of \( V(Y) \) in the case of Example 3.19](image)

**Proof.** Let \( Y \) be as in Proposition 3.18 and let us show that the definition of the edges does not depend on the choice of \( f \) in the atlas.

First, let \( y_1, y_2 \in Y \) and \( y, z \in Y \) such that \( y_1 \) and \( y_2 \) belong to \( B(y, r_p) \cap B(z, r_p) \). Then, take two local maps \( f_y, f_z \) in \( \mathfrak{A} \) associated to \( y \) and \( z \) respectively. Then \( d(y, z) \leq 2r_p \) and by Lemma 3.12 there exists \( \alpha \in \text{Isom}(X) \) verifying eq. (6). Hence, by \( \text{Isom}(X) \)-equivariance of \( q \) we get

\[
d_X(qf_z(y_1), qf_z(y_2)) = d_X(q(\alpha f_z(y_1)), q(\alpha f_z(y_2))) = d_X(qf_y(y_1), qf_y(y_2)).
\]
Thus $d_X(qf_z(y_1), qf_z(y_2)) = 1$ if and only if $d_X(qf_y(y_1), qf_y(y_2)) = 1$ and the definition of edges between two vertices of $Y$ does not depend on the choice of local isometry.

Now take $y \in Y$ and let $P \subset Y$ be a print. Let $z$ and $z'$ such that $y$ and $P$ are contained in $B(z, r_P) \cap B(z', r_P)$ and take $f$ (resp. $f'$) in $\mathcal{A}$ defined on $B(z, R)$ (resp. $B(z', R)$). Then $d(z, z') \leq 2r_P$ and by Lemma 3.12 there exists $a \in \text{Isom}(X)$ verifying eq. (6). Hence,

$$d_X(qf(y), x) = d_X(\rho(a)qf(y), \rho(a)(x)) = d_X(qf'(y), \rho(a)(x)).$$

If $x$ is the source of $qf(P)$ then, by Lemma 3.9 we get

$$\mathcal{P}(\rho(a)(x)) = \rho(a)(\mathcal{P}(x)) = \rho(a)qf(P) = qf'(P).$$

Thus, the existence of an edge between $y$ and $P$ in $Y$ does not depend of the choice of map in $\mathcal{A}$.

Finally, take $P_1, P_2 \subset Y$ two prints and let $z, z'$ in $Y$ and $f \in \mathcal{A}$ (resp. $f'$) defined on $B_Y(z, R)$ (resp. $B_Y(z', R)$) such that $P_1, P_2 \subset B_Y(z, r_P) \cap B_Y(z', r_P)$. Again $d(z, z') \leq 2r_P$ and by Lemma 3.12 there exists $a \in \text{Isom}(X)$ verifying eq. (6). Hence if $x_1$ is the source of $qf(P_1)$ and $x_2$ the source of $qf(P_2)$, then $d(x_1, x_2) = 1$ if and only if $d(\rho(a)(x_1), \rho(a)(x_2)) = 1$. Moreover, by Lemma 3.9

$$\forall i = 1, 2 \quad \mathcal{P}(\rho(a)(x_i)) = \rho(a)(\mathcal{P}(x_i)) = \rho(a)qf(P_i) = qf'(P_i).$$

Hence the existence of an edge between $P_1$ and $P_2$ in $Y$ does not depend of the choice of map in $\mathcal{A}$.  

\section{FROM ONE GRAPH TO THE OTHER}

In this section we prove the isometry between the graph $Y$ built and the Bruhat-Tits building and show that it induces an isometry between $X$ and $Y$.

\subsection{Isometry with the building}

We can now prove that $Y$ is isometric to the Bruhat-Tits building. Recall that $r_\mathcal{A}$ is the radius used to define our atlas $\mathcal{A}$ (see Lemma 3.11) and $r_P$ is the radius used to define prints in $Y$ (see Definition 3.13). These constants verify $R > r_\mathcal{A} > 3r_P > r_P$.

\begin{lemma}
Let $R_X > 0$. If $r_P$ (and hence $R$) is large enough, then $Y$ is $R_X$-locally $X$.
\end{lemma}

To prove this lemma, we define explicitly the local isometries on balls of radius $R_X$ and prove that these maps are well defined injections. Then, we compute the
minimal value of $r_p$ necessary for these applications to be surjective on balls of radius $R_X$. We conclude by showing that these maps preserve the distance.

**Proof.** Let $v \in V(Y)$. If $v \in V(Y)$ let $f \in \mathfrak{A}$ be the isometry defined on $B_Y(v, R)$. If $v$ is a print $P$ let $y$ and $f \in \mathfrak{A}$ be such that $P$ is a print associated to $y$ and $f$. Our goal is to show that the map

$$
\varphi_f : \begin{cases} 
B_Y(v, R_X) & \rightarrow X, \\
z \in Y & \mapsto qf(y), \\
Q & \mapsto x \text{ where } P(x) = qf(Q),
\end{cases}
$$

is an isometry.

By Proposition 3.6, it is a well defined map. Moreover, using the injectivity of $q$ and Proposition 3.6 and eq. (3) we get that $\varphi_f$ is an injective map.

Now, recall that since $q$ is a quasi-isometry, two elements $q(x_1)$ and $q(x_2)$ joined by an edge in $X$ might be at distance greater than 1 in $X$. If we want to prove that $\varphi_f$ is surjective on $B_X(\varphi_f(v), R_X)$ and preserves the distance, we have to show that there exists a radius $r_p$ allowing us to “reconstruct” all the edges of $B_X(\varphi_f(v), R_X)$ in $B_Y(v, R_X)$. Let $L, \varepsilon > 0$ be such that $q$ is a $(L, \varepsilon)$-quasi-isometry. We distinguish three cases, represented in Figure 11.

If $\chi_1, \chi_2 \in \text{im}(q)$, then let $x_1, x_2 \in X$ such that $q(x_1) = \chi_1$. They verify $d_X(x_1, x_2) \leq Ld_X(\chi_1, \chi_2) + \varepsilon$. This case is represented in Figure 11a.

If $\chi_1 \in \text{im}(q)$ and $\chi_2 \notin \text{im}(q)$, let $x_1 = q^{-1}(\chi_1)$. For all $x_2 \in X$ such that $q(x_2) \in P(\chi_2)$, we have (see Figure 11b)

$$d_X(x_1, q(x_2)) \leq 1 + d_X(\chi_1, x_2) \Rightarrow d_X(x_1, x_2) \leq Ld_X(\chi_1, \chi_2) + L + \varepsilon.$$

If $\chi_1, \chi_2 \notin \text{im}(q)$, let $x_i \in X$ such that $q(x_i) \in P(\chi_i)$ for $i = 1, 2$. Then (see Figure 11b)

$$d_X(x_1, q(x_2)) \leq 2 + d_X(\chi_1, x_2) \Rightarrow d_X(x_1, x_2) \leq Ld_X(\chi_1, \chi_2) + 2L + \varepsilon.$$

Hence, assume $r_p > LR_X + 2L + \varepsilon$ and let us show that $\varphi_f$ is an isometry.

Let $\chi \in B_X(\varphi_f(v), R_X)$, by choice of $r_p$ either $\chi \in \text{im}(q)$ and there exists $z \in B_Y(y, r_p)$, $y \in B_Y(v, r_p)$, such that $qf(z) = \chi$ or $\chi \notin \text{im}(q)$ and there exists $P \subseteq B_Y(y, r_p)$ such that $qf(P) = P(\chi)$. Hence, in both cases $\chi \in \text{im}(\varphi_f)$ and thus, $\varphi_f$ is a bijection from $B_Y(v, R_X)$ to $B_X(\varphi_f(v), R_X)$. Now take $v_1, v_2$ in $B_Y(v, R_X)$ at distance 1 in $Y$ and let $(w_0 = v_1, w_1, \ldots, w_l = v_2)$ be a geodesic in $Y$. By definition of $Y$ and choice of $r_p$, for all $i \in \{0, \ldots, l - 1\}$ if there is an edge between $w_i$ and $w_{i+1}$, then $d(\varphi_f(w_i), \varphi_f(w_{i+1})) = 1$. Hence $d_X(\varphi_f(v_1), \varphi_f(v_2)) \leq 1$. To get the reversed inequality, take $\chi_1, \chi_2$ in $B_X(\varphi_f(v), R_X)$. Since $\varphi_f$ is bijective there exists $v_0, \ldots, v_l$ in $Y$ such that $(\varphi_f(v_0), \ldots, \varphi_f(v_l))$ is a geodesic between $\chi_1$ and $\chi_2$. Again, by definition of $Y$ and choice of $r_p$, an edge between $\varphi_f(v_1)$ and $\varphi_f(v_{l+1})$ gives an edge between $v_1$ and $v_{l+1}$ in $Y$ and thus $d_Y(v_1, v_2) \leq 1$.

Hence, if $r_p > LR_X + 2L + \varepsilon$ then $\varphi_f$ is an isometry. \qed
The LG-rigidity of the building will give us a covering from $\mathcal{X}$ to $\mathcal{Y}$. In order to obtain an isometry we need to prove (by Proposition 2.12) that $\mathcal{Y}$ is simply connected at the same scale as $\mathcal{X}$.

**Lemma 4.2**

If $R_X$ (and hence $R$) is large enough, then $\mathcal{Y}$ is simply connected at scale 3.

We first prove that $\mathcal{Y}$ is quasi-isometric to $Y$ and use it to show that $\mathcal{Y}$ is simply connected at some scale $k'$. We conclude using the contractibility of the building and the fact that $\mathcal{Y}$ is locally the same as the building. But before looking at the detail of the proof, let us make a remark.

**Remark 4.3.** Let $P$ be a print associated to some $z \in \mathcal{Y}$ and $f \in \mathcal{A}$ and let $y \in P$. If $x$ is the source of $qf(P)$, then $d_\mathcal{Y}(P, y) = d_X(x, qf(y)) = 1$.

**Proof of Lemma 4.2.** Let us show that $\mathcal{Y}$ is quasi-isometric to $Y$. Define $\pi : \mathcal{Y} \rightarrow Y$ such that if $y \in \mathcal{V}(Y)$ then $\pi(y) = y$ and if $P$ is a print then $\pi(P) = y$ for some $y \in \mathcal{P}$ arbitrarily chosen. Let $(v_0, \ldots, v_m)$ be a geodesic in $\mathcal{Y}$ and for all $i \in \{0, \ldots, m\}$ define $y_i := \pi(v_i)$ and $f_i$ to be the isometry of $\mathcal{A}$ associated to $y_i$. Using that $q$ is a $(L, \epsilon)$-quasi-isometry, we get

$$d_\mathcal{Y}(\pi(v_0), \pi(v_m)) = d_Y(y_0, y_m) \leq \sum_{i=0}^{m} d_Y(y_i, y_{i+1}),$$

$$\leq \sum_{i=0}^{m} \left[Ld_X(qf_i(y_i), qf_i(y_{i+1})) + \epsilon\right].$$

Now let $i \in \{0, \ldots, m\}$. If $v_i$ is a print, denote by $x_i$ the source of $qf(v_i)$ and if $v_i$ belongs to the copy of $V(Y)$ contained in $\mathcal{Y}$ let $x_i := qf_1\pi(v_i)$. Then $d_\mathcal{Y}(v_i, v_{i+1}) = d_X(x_i, x_{i+1})$ for all $i$. Thus, using remark 4.3, we get

$$d_X(qf_i(y_i), qf_i(y_{i+1})) \leq d_X(qf_i(y_i), x_i) + d_X(x_i, x_{i+1}) + d_X(qf_i(y_{i+1}), x_{i+1}),$$

Figure 11: The three cases ($\text{im}(q)$ is represented by the blue vertices)
\[ \leq 2 + d_X(x_i, x_{i+1}) = 2 + d_Y(v_i, v_{i+1}). \]

Since \( d_Y(v_i, v_{i+1}) = 1 \), we obtain
\[
d_Y(\pi(v_0), \pi(v_m)) = d_Y(y_0, y_m) \leq \sum_{i=0}^{m} [L2 + Ld_Y(v_i, v_{i+1}) + \epsilon],
= (3L + \epsilon)m = (3L + \epsilon)d_Y(v_0, v_m).
\]

Now let \( v, v' \in \mathcal{Y} \) and let \( (\pi(v) = z_0, \ldots, \pi(v') = z_1) \) be a geodesic in \( \mathcal{Y} \). For all\( i \in \{0, \ldots, l\} \) take \( f_i \in \mathfrak{A} \) the isometry associated to \( z_i \). Then
\[
d_y(v, v') \leq d_y(v, z_0) + \sum_{i=0}^{l-1} d_y(z_i, z_{i+1}) + d_y(z_l, v').
\]

But by remark 4.3 if \( v \) (resp. \( v' \)) is a print then \( d_y(v, z_0) = 1 \) (resp. \( d_y(v', z_1) = 1 \)). And if \( v \) (resp. \( v' \)) belongs to \( V(\mathcal{Y}) \) then \( v = z_0 \) (resp. \( v' = z_1 \)). Thus both \( d_y(v, z_0) \) and \( d_y(v', z_1) \) are always smaller than 1. Hence,
\[
d_y(v, v') \leq 2 + \sum_{i=0}^{l-1} d_y(z_i, z_{i+1}) = 2 + \sum_{i=0}^{l-1} d_X(qf'_1(z_i), qf'_1(z_{i+1})),
\leq 2 + \sum_{i=0}^{l-1} [Ld_Y(z_i, z_{i+1}) + \epsilon],
= 2 + (L + \epsilon)l = 2 + (L + \epsilon)d_Y(\pi(v), \pi(v')).
\]

Thus \( \pi \) is a quasi-isometry between \( \mathcal{Y} \) and \( \mathcal{Y} \). Hence Proposition 2.13 implies that there exists \( k' \in \mathbb{N}^\ast \) such that \( \mathcal{Y} \) is simply-connected at scale \( k' \).

Finally, let \( \ell \) be loop in \( \mathcal{Y} \) of length less than \( k' \). If \( R_X \) is large enough then \( \ell \) is contained in some ball \( B \) in \( \mathcal{Y} \). By Lemma 4.1 there exists a local isometry \( \varphi \) from \( B \) to some ball \( B' \) in \( X \). But \( \varphi(\ell) \) is contractible inside its convex hull, by Claim 2.7. In particular it is simply-connected. Since \( X \) is 3-simply-connected and if \( R_X \) is large enough, the convex hull of \( \varphi(\ell) \) is contained in the complex obtained by gluing triangles on all the loops of length 3 in \( B \). Which, by local isometry with \( B \), proves the wanted assertion.  

Thanks to the previous lemma, we can now use the rigidity of the Bruhat-Tits building.

**Proposition 4.4** 
If \( R_X \) (and hence \( R \)) is large enough, then \( \mathcal{Y} \) is isometric to \( X \).

**Proof.** Recall that we have \( R > r_A > 3r_p > r_p > 3R_X + 2L + \epsilon > R_X \).
By Theorem 1.13, the building \( X \) is LG-rigid. Moreover, since its isometry group is transitive Proposition 2.12 gives us the existence of some radius \( R_{sc} > 0 \) such that every graph which is 3-simply connected and \( R_{sc} \)-locally \( X \) is isometric to \( X \).
By definition of the edges on $Y$, this graph is simply connected at scale 3. Taking $r_p$ (and hence $R$) large enough so that $R_X \geq R_{sc}$ the preceding paragraph combined with Lemma 4.1 give us the existence of an isometry between $X$ and $Y$. 

4.2 Change of local map, change of global isometry

Let $y \in Y$ and $f_y \in A$ be the isometry defined on $B(y, R)$. Let

$$
\varphi_y : \begin{cases} 
B_y(y, R_X) & \to X \\
 z \in Y & \mapsto qf_y(z) \\
 Q & \mapsto x 
\end{cases}
$$

(8)

where $P(x) = qf_y(Q)$.

**Lemma 4.5**

Let $y$ and $z$ be neighbours in $Y$ and $a \in H_0$ such that $f_y f_z^{-1}$ coincide with $a$ on $B_X(f(z), r_A)$. If $R_X$ is large enough, then $\varphi_y \varphi_z^{-1}$ coincide with $\rho(a)$ on $B_X(\varphi_z(z), 2)$.

**Proof.** Let $y$ and $z$ be neighbours in $Y$ and $a \in H_0$ such that $f_y f_z^{-1}$ coincide with $a$ on $B_X(f(z), r_A)$. If $R_X$ (and hence $R$) is large enough, then $B_y(z, 2)$ is contained in $B_y(y, R_X)$. Thus, $\varphi_y \varphi_z^{-1}$ is well defined on $B_X(\varphi_z(z), 2)$.

Let $v \in B_y(z, 2)$. If $v \in V(Y)$, then

$$
\varphi_y(v) = qf_y(v) = qaf_z(v) = \rho(a)qf_z(v) = \rho(a)\varphi_z(v).
$$

If $v = P$ with $P \subset Y$ a print, then

$$
P(\varphi_y(v)) = qf_y(P) = qaf_z(P) = \rho(a)qf_z(P) = P(\rho(a)\varphi_z(v)),
$$

Thus $\varphi_y(v) = \rho(a)\varphi_z(v)$, since the print determines the vertex. Hence the result. 

Now let $r_X > 0$. If $R_X$ is large enough then, by SLG-rigidity of $X$ there exists an isometry $\iota_y$ from $Y$ to $X$ that coincides with $\varphi_y$ on $B(y, r_X)$. Thus, the lemma above allows us to work with a set of isometries from $Y$ to $X$ that differs only by a multiplication by an element of $PSL_n(K)$.

**Lemma 4.6**

If $y$ and $z$ belong to $Y$ and $R_X$ is large enough, then $\iota_y \iota_z^{-1} \in PSL_n(K)$. Hence for all $y \in Y$, the isometry $\iota_y$ sends the copy of $V(Y)$ contained in $Y$ to $\text{im}(q)$ and sends prints contained in $Y$ to vertices in $X \setminus \text{im}(q)$.
Proof. Let \( y \) and \( z \) be neighbours in \( Y \). Since \( t_y t_z^{-1} \) is an isometry of \( X \) it permutes the \( \text{PSL}_n(\mathbb{K}) \)-orbits. Recall that \( t_y \) coincides with \( \varphi_y \) on \( B(y, r_X) \). Hence, if \( r_X \) (and hence \( R \)) is large enough, then \( B_y(z, 2) \) is contained in \( B_y(y, r_X) \), thus
\[
(t_y t_z^{-1})|_{B_X(t_z(z), 2)} = \varphi_y \varphi_z^{-1}.
\]

But \( \varphi_y \varphi_z^{-1} \) coincides with an element of \( \text{PSL}_n(\mathbb{K}) \) on \( B_X(\varphi_z(z), 2) \), by Lemma 4.5. Hence \( t_y t_z^{-1} \) restricted to a ball of radius 2 preserves the \( \text{PSL}_n(\mathbb{K}) \)-orbits and thus belongs to \( \text{PSL}_n(\mathbb{K}) \).

Now take \( y \) and \( z \) in \( Y \) (not necessarily neighbours). Let \( (y_0 = y, y_1, \ldots, y_l = z) \) be a geodesic in \( Y \). By the preceding paragraph, there exists a sequence \( \alpha_1, \ldots, \alpha_l \) of elements in \( \text{PSL}_n(\mathbb{K}) \) such that
\[
\forall i \in \{1, \ldots, l\} \quad t_{y_i} t_{y_{i-1}}^{-1} = \alpha_i.
\]

Thus, recalling that \( z = y_l \) and \( y = y_0 \), we get \( t_z = \alpha_1 \cdots \alpha_l t_y \). Which proves the first assertion of the lemma.

Let us now prove the second part of the lemma. Let \( y \in Y \) and \( v \in Y \). There exists \( z \in Y \) such that \( v \in B_y(z, 2) \), and using the paragraph above, there exists \( \alpha \in \text{PSL}_n(\mathbb{K}) \) such that \( t_y = \alpha t_z \). In particular, since \( v \) belongs to \( B_y(z, R_X) \),
\[
t_y(v) = \alpha t_z(v) = \alpha \varphi_z(v).
\]

By definition of \( \varphi_z \), if \( v \in V(Y) \) then \( \varphi_z(v) \) belongs to \( \text{im}(q) \) and if \( v = P \) with \( P \subset Y \) a print, then \( \varphi_z(v) \) belongs to \( X \setminus \text{im}(q) \). This finishes the proof of the lemma.

Now we have all the tools we need to prove the isometry between \( Y \) and \( X \).

### 4.3 Isometry from \( Y \) to \( X \)

Let \( \kappa \) be the natural injection of \( Y \) in \( Y_Z \) and \( t \) an isometry given by Proposition 4.4. With the objects constructed so far we get the diagram in Figure 12.
The aim of this section is to prove the following result.

**Proposition 4.7**

For $R_X$ large enough, the graphs $Y$ and $X$ are isometric.

Let us discuss the strategy of the proof. Using the preceding section, we chose an isometry $\iota$ from $Y$ to $X$ that coincides with a $\varphi_y$ on a small ball. Then, we show that $\kappa^{-1}q$ is locally an isometry, viz. there exists a radius $r_Y$ such that $q^{-1}\iota\kappa$ restricted to any ball of radius $r_Y$ preserves the distance. We conclude by showing that it forces $\kappa^{-1}q$ to be an isometry.

**Proof of Proposition 4.7.** By Lemma 4.6, for any $y \in Y$ the map $q^{-1}\iota_y\kappa$ is well defined. Now fix $y_0 \in Y$ and consider $\iota := \iota_{y_0}$. We want to prove that $q^{-1}\iota\kappa$ restricted to small balls preserves the distance. Then we will show that it is an isometry from $Y$ to $X$.

**Claim 4.8.** Let $y \in Y$ and $r_Y \geq 1$. If $R$ is large enough, then $q^{-1}\iota\kappa$ restricted to $B_Y(y, r_Y)$ preserves the distance.

**Proof of the claim.** Let $r_Y \geq 1$ and recall that we have $R > r_A > 3r_p > r_p > 3R_X + 2L + \varepsilon > R_X > r_X$. Let $y \in Y$ and recall that $L$ and $\varepsilon$ are constants such that $q$ is a $(L, \varepsilon)$-quasi-isometry. If $r_X \geq Lr_Y + \varepsilon$ (and hence if $R$ is large enough) then $\kappa(B_Y(y, r_Y))$ is included in $B_Y(y, r_X)$. Indeed if $z \in B_Y(y, r_Y)$ then

$$d_X(qf_y(y), qf_y(z)) \leq Ld_X(f_y(y), f_y(z)) + \varepsilon = Ld_Y(y, z) + \varepsilon \leq Lr_Y + \varepsilon \leq r_X.$$ 

Thus $\varphi_y(\kappa(z)) = qf_y(z)$ and

$$d_y(\kappa(y), \kappa(z)) = d_X(\varphi_y(\kappa(y)), \varphi_y(\kappa(z))) = d_X(qf_y(y), qf_y(z)) \leq R_X.$$ 

Now, recall that $H_0 = \rho^{-1}PSL_n(\mathbb{R})$. Then, by Lemma 4.6 there exists $a_y \in H_0$ such that $\iota_y^{-1} = \rho(a_y)$. Hence, using the equivariance of $q$ we get that for all $z_1$ and $z_2$ in $B_Y(y, r_Y)$

$$d_X(q^{-1}\iota\kappa(z_1), q^{-1}\iota\kappa(z_2)) = d_X(a_yq^{-1}\iota\kappa(z_1), a_yq^{-1}\iota\kappa(z_2))$$

$$= d_X(q^{-1}\rho(a_y)\iota\kappa(z_1), q^{-1}\rho(a_y)\iota\kappa(z_2))$$

$$= d_X(q^{-1}\iota_y\kappa(z_1), q^{-1}\iota_y\kappa(z_2)).$$ 

But $z_1$ and $z_2$ belong to $B_Y(y, r_Y)$, hence for $i = 1, 2$ we have $\iota_y\kappa(z_i) = qf_y(z_i)$. Thus,

$$d_X(q^{-1}\iota\kappa(z_1), q^{-1}\iota\kappa(z_2)) = d_X(q^{-1}qf_y(z_1), q^{-1}qf_y(z_2))$$

$$= d_X(f_y(z_1), f_y(z_2)) = d_Y(z_1, z_2).$$ 

Thus $q^{-1}\iota\kappa$ restricted to $B_Y(y, r_Y)$ preserves the distance. 

\[\Box\]
5 Application to \( p \)-adic lattices

Let’s show that the claim forces \( q^{-1}\iota \kappa \) to be an isometry from \( Y \) to \( X \). Take \( r_Y \geq 2 \) and let \( y, y' \in Y \) and \((y_0 = y, y_1, \ldots, y_l = y')\) be a geodesic in \( Y \). Since for all \( i \) the vertices \( y_i \) and \( y_{i+1} \) are adjacent, then Claim 4.8 implies that \( d_X(q^{-1}\iota \kappa(y_i), q^{-1}\iota \kappa(y_{i+1})) = 1 \). Hence

\[
d_X\left(q^{-1}\iota \kappa(y), q^{-1}\iota \kappa(y')\right) = \sum_{i=0}^{l-1} d_X\left(q^{-1}\iota \kappa(y_i), q^{-1}\iota \kappa(y_{i+1})\right).
\]

Moreover, if \((x_0 = q^{-1}\iota \kappa(y), x_1, \ldots, x_m = q^{-1}\iota \kappa(y'))\) is a geodesic in \( X \), then by bijectivity of \( q^{-1}\iota \kappa \) there exists \( z_i \in Y \) such that \( q^{-1}\iota \kappa(z_i) = x_i \) for all \( i \) in \( \{1, \ldots, m-1\} \). Denote \( z_0 = y \) and \( z_m = y' \). Since for all \( i \) the vertices \( x_i \) and \( x_{i+1} \) are adjacent, then Claim 4.8 implies that \( d_X(z_i, z_{i+1}) = d_X(q^{-1}\iota \kappa(z_i), q^{-1}\iota \kappa(z_{i+1})) \). Thus

\[
d_Y(y, y') \leq \sum_{i=0}^{m-1} d_Y(z_i, z_{i+1}) = \sum_{i=0}^{m-1} d_X\left(q^{-1}\iota \kappa(z_i), q^{-1}\iota \kappa(z_{i+1})\right),
\]

\[
= \sum_{i=0}^{m-1} d_X(x_i, x_{i+1}) = m.
\]

We conclude by the proof of Theorem 1.18.

**Proof of Theorem 1.18.** Let \( n \neq 3 \) and \( X \) verifying the hypothesis of Theorem 1.18.

If \( n = 2 \) then \( X \) is the \((p+1)\)-regular tree, thus by Example 1.5 if \( X \) is quasi-isometric to \( X \) then \( X \) is LG-rigid.

If \( n \geq 4 \), let \( k \in \mathbb{N} \) such that \( X \) is simply connected at scale \( k \). Then by Proposition 4.7 for \( R \) large enough, any \( k \)-simply-connected graph \( Y \) being \( R \)-locally the same as \( X \) is isometric to \( X \). Thus \( X \) is LG-rigid. Finally for any \( n \neq 3 \), since \( X \) is assumed transitive it is actually SLG-rigid by Proposition 1.8.

5 APPLICATION TO \( p \)-ADIC LATTICES

In this section we prove Theorem 1.17 which we recall below.

**Corollary 5.1** \( \) Let \( n \neq 3 \) and \( K \) be a non-Archimedean skew field of characteristic zero.

The torsion-free lattices of \( \text{SL}_n(K) \) are SLG-rigid.

Let \( n \neq 3 \), let \( K \) be a non-Archimedean skew field of characteristic zero and \( \Gamma \subseteq \text{SL}_n(K) \) be a lattice without torsion. Denote by \((\Gamma, S)\) one of its Cayley graphs. Recall that any lattice in \( \text{SL}_n(K) \) is uniform (i.e. cocompact).
5 Application to $p$-adic lattices

5.1 Quasi-isometry between the lattice and the building

To show the corollary, we first check that the lattice is quasi-isometric to the building. Then, using a famous result of Kleiner and Leeb we show that the isometry group of the lattice acts on the building and that the quasi-isometry can be chosen to be equivariant under this action.

**Lemma 5.2**

Let $\Lambda$ be a lattice of $\text{SL}_n(\mathbb{K})$. Then $\Lambda$ is quasi-isometric to $X$.

**Proof.** First, recall that any lattice in $\text{SL}_n(\mathbb{K})$ is uniform, viz. cocompact (see for example [BQ14]).

Since $\Lambda$ is a lattice of $\text{SL}_n(\mathbb{K})$, there is a natural action on the Bruhat-Tits building induced by the action of $\text{PSL}_n(\mathbb{K})$. Moreover, since $\Lambda$ is cocompact and the $\text{PSL}_n(\mathbb{K})$ action has exactly $n$ orbits, the $\Lambda$ action is also cocompact. Hence by the Svarc-Milnor’s lemma $\Lambda$ is quasi-isometric to $X$.

By a result of Kleiner and Leeb [KL97] and Cornulier [Cor18, Theorem 3.B.1] applied to our lattice $\Gamma$, this quasi-isometry implies the existence of a homomorphism from $\text{Isom}(\Gamma, S)$ to $\text{Isom}(X)$ and a quasi-isometry from $(\Gamma, S)$ to $X$ which is $\text{Isom}(\Gamma, S)$-equivariant. Since $\Gamma$ is assumed to be torsion-free, we can refine the informations about these two applications.

**Lemma 5.3**

Let $\Lambda$ be a lattice of $\text{SL}_n(\mathbb{K})$ and $T$ a symmetric generating set. If $\Lambda$ is torsion-free, then there exists an injective homomorphism

$$\rho : \text{Isom}(\Lambda, T) \to \text{Isom}(X),$$

and an injective quasi-isometry which is $\text{Isom}(\Lambda, T)$-equivariant

$$q : (\Lambda, T) \to X.$$

**Proof.** Since we assumed that $\Lambda$ has no torsion element, by Proposition 1.20 the isometry group of $(\Lambda, T)$ contains no non-trivial compact normal subgroup. Hence the morphism $\rho$ given by Kleiner-Leeb’s theorem is injective.

Assume that there exist $\lambda_1, \lambda_2 \in \Lambda$ such that $\lambda_1 \neq \lambda_2$ and $q(\lambda_1) = q(\lambda_2)$. Then, the equivariance of $q$ implies that

$$q \left( \left\{(\lambda_1 \lambda_2^{-1})^n : n \in \mathbb{N}\right\} \right) = q(e),$$

which contradicts the fact that $q$ is a quasi-isometry.

---

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5.2 Relation between the isometry groups

To apply Theorem 1.18, we still need to check that $\text{Isom}(\Gamma, S)$ is of finite index in $\text{Isom}(X)$. As stated in the lemma below, this is not always the case: the lattice’s isometry group can also be discrete. But as we will see in Section 5.3 we will be able to prove the rigidity of the lattice in that case too.

**Lemma 5.4**

Using the previous notations,
- Either $\text{Isom}(\Gamma, S)$ is discrete.
- Or $\text{Isom}(\Gamma, S)$ is of finite index in $\text{Isom}(X)$ and contains $\text{PSL}_n(\mathbb{K})$.

Before proving this lemma, let us recall a useful consequence of a theorem of Benoist and Quint. The original and more general statement can be found in [BQ14, Corollary 4.5].

**Proposition 5.5 (Benoist, Quint [BQ14])**

Let $G$ be a $p$-adic Lie group and $H$ be a finite covolume closed subgroup of $G$, with Lie algebra $\mathfrak{h}$. If $G$ has no proper cocompact normal subgroup, then $G$ normalizes $\mathfrak{h}$.

**Proof of Lemma 5.4.** Let $G = \text{PSL}_n(\mathbb{K})$ and $H = \text{Isom}(\Gamma, S) \cap G$ and note $\mathfrak{h} := \text{Lie}(H)$ and $\mathfrak{g} := \text{Lie}(G)$ their respective Lie algebras. Since $\Gamma$ is a lattice in $\text{SL}_n(\mathbb{K})$, we get that $\rho(\Gamma) \cap \text{PSL}_n(\mathbb{K})$ is a lattice in $\text{PSL}_n(\mathbb{K})$. Hence $H$ contains the uniform lattice $\rho(\Gamma) \cap G$ of $G$, thus $H$ has finite covolume in $\text{PSL}_n(\mathbb{K})$.

If $\mathbb{K}$ is a non-Archimedean local skew field of characteristic zero then it is an extension of $\mathbb{Q}_p$ for some prime $p$ (see for example [dlST16, Section 1]). In particular $G$ is a $p$-adic Lie group. Thus the above property applied to $G$ and $H$ implies that $G$ normalises $\mathfrak{h}$, in other words $\mathfrak{h}$ is an ideal of $\mathfrak{g}$. Since $\mathfrak{g}$ is simple, we get that $\mathfrak{h}$ is either trivial or the full Lie algebra $\mathfrak{g}$. If $\text{Isom}(\Gamma, S)$ isn’t discrete, then it is a closed subgroup of $\text{Isom}(X)$. Hence $H$ is a closed subgroup of $G$ and its Lie algebra is non-trivial. By the previous point it can only be $\mathfrak{g}$. Hence, it implies that $H$ is an open subgroup of $G$. Since it is also cocompact, it is necessarily of finite index in $G$. Thus, we get that $\rho(\text{Isom}(\Gamma, S))$ is of finite index in $\text{Isom}(X)$.

Let’s show that $\text{PSL}_n(\mathbb{K}) \leq \rho(\text{Isom}(\Gamma, S))$. First assume that $\rho(\text{Isom}(\Gamma, S))$ is strictly contained in $\text{PSL}_n(\mathbb{K})$. Since these two groups are of finite index in $\text{Isom}(X)$, we get that $\rho(\text{Isom}(\Gamma, S))$ is of finite index in $\text{PSL}_n(\mathbb{K})$. But then the core:

$$
\bigcap_{g \in \text{PSL}_n(\mathbb{K})} g \cdot \rho(\text{Isom}(\Gamma, S)) \cdot g^{-1}
$$

of $\rho(\text{Isom}(\Gamma, S))$ is itself of finite index in $\text{PSL}_n(\mathbb{K})$ (and different from $\text{PSL}_n(\mathbb{K})$), which contradicts the simplicity of $\text{PSL}_n(\mathbb{K})$.

Now, let’s go back to the general case. Assume that $\text{PSL}_n(\mathbb{K})$ isn’t included in $\rho(\text{Isom}(\Gamma, S))$ and remark that:

$$
\mathfrak{h} = \text{Lie}(\text{Isom}(X)) = \text{Lie}(\text{PSL}_n(\mathbb{K})).
$$
In particular $\rho(\text{Isom}(\Gamma, S))$ is “locally” $\text{PSL}_n(\mathbb{K})$ so, up to apply what precedes to an open set centered on $e_\Gamma$ sufficiently small of $\rho(\text{Isom}(\Gamma, S))$, we obtain a contradiction. Hence $\text{PSL}_n(\mathbb{K})$ is contained in $\rho(\text{Isom}(\Gamma, S))$. \hfill \Box

5.3 Rigidity of $p$-adic lattices

We conclude by the proof of Corollary 5.1.

Proof of Corollary 5.1. Let $n \neq 3$ and $p$ be a prime. Let $\Gamma$ be a torsion-free lattice of $\text{PSL}_n(\mathbb{K})$ and $S$ be a symmetric generating part.

If $n = 2$, then $X$ is the $(p + 1)$-regular tree. Since by Lemma 5.2, the graph $(\Gamma, S)$ is quasi-isometric to $X$, Example 1.5 implies that $(\Gamma, S)$ is LG-rigid.

Assume now that $n > 3$. If $\text{Isom}(\Gamma, S)$ is discrete the LG-rigidity of the lattice is given by Theorem 1.9.

If $\text{Isom}(\Gamma, S)$ is non-discrete, then by Lemma 5.4 it has finite index in $\text{Isom}(\mathbb{X})$ and in this case the hypothesis of Theorem 1.18 are satisfied, hence the rigidity of the lattice.

Finally, for all $n \neq 3$ the lattice $\Gamma$ acts transitively on $(\Gamma, S)$ thus, by Proposition 1.8, it is SLG-rigid. \hfill \Box

6 Conclusion and open problems

Our main result is proved for graphs quasi-isometric to the Bruhat-Tits building of $\text{PSL}_n(\mathbb{K})$ and the key idea of the proof is to use the rigidity of this building to “transfer it” to the graph quasi-isometric thereto. One can ask wether we can generalize this idea to other LG-rigid graphs.

Question 6.1. Let $\mathcal{G}$ be quasi-isometric to a LG-rigid graph $\mathcal{H}$, both having cocompact isometry group. If the quasi-isometry is $\text{Isom}(\mathcal{G})$-equivariant, is $\mathcal{G}$ LG-rigid?

Remark that if $\mathcal{H}$ and $\mathcal{G}$ are two Cayley graphs of the same group, we can chose $\mathcal{H}$ to be LG-rigid and $\mathcal{G}$ to be non-rigid (see the discussion below Counter-example 1.6 for more details). In that case the hypothesis of the preceding question are satisfied without $\mathcal{G}$ being LG-rigid. Thus, more restrictive hypothesis will be needed to get the rigidity of $\mathcal{G}$.

Our result on lattices is proved for $n \neq 3$; when $n = 3$ we don’t know (yet) the answer. Indeed, our proof is based on the rigidity of the Bruhat-Tits building of $\text{PSL}_n(\mathbb{K})$, a result known to be true only for $n \neq 3$. In the $n = 3$ case, a lot of flexibility seems to be allowed (see for example [BP07]) obstructing any local recognizability result. Hence the following question:

Question 6.2. Are torsion-free lattices of $\text{SL}_3(\mathbb{K})$ LG-rigid?

Lattices in $p$-adic Lie groups can be viewed as particular cases of $S$-arithmetic lattices.
6 Conclusion and open problems

Definition 6.3
Let $S$ be a set of prime.

We say that $\Gamma$ is an **$S$-arithmetic** lattice if it’s a lattice in a product of the form $\prod_{i} G_i$ where $G_i$ is either a real Lie group or a $p$-adic Lie group for $p \in S$.

Hence, one we can ask what happens in that more general case.

Question 6.4. Are torsion-free $S$-arithmetic lattices LG-rigid?

A result by Bader, Furman and Sauer [BFS20, Theorem B] can be used to deal with irreducible torsion-free $S$-arithmetic lattices. Indeed, if the product $\prod_{i} G_i$ contains at least a non-compact real factor, then the aforementioned theorem implies that the isometry group of a Cayley graph of $\Gamma$ is discrete. Thus, by Theorem 1.9 the lattice is LG-rigid. Now, if the product contains a compact real factor then the isometry group of the Cayley graph might not be discrete and in that case, the problem is still open.

When the lattice is reducible, we now know that the projection on the $p$-adic factors gives LG-rigid lattices. Moreover, if we suppose the real factors to be simple and connected, then a result by de la Salle and Tessera [dlST19] shows that the projection on these factors are also LG-rigid. Hence it remains to understand how to combine these results on the factors in order to get a result on the product.
REFERENCES


NOTATIONS INDEX

² Atlas of isometries from $Y$ to $X$.
A An apartment in $X$.
$(\Gamma, S)$ Cayley graph of $\Gamma$ with respect to the generating part $S$.
$H_0$ The group $\rho^{-1}(\text{PSL}_n(\mathbb{K}))$.
Isom($\mathcal{G}$) Isometry group of $\mathcal{G}$.
t$_y$ Isometry from $\mathcal{Y}$ to $X$ based at $y$ (see page 26).
$\kappa$ Natural injection of $Y$ in $\mathcal{Y}$ (see Section 4.3).
$[L]$ Class modulo homothety of the lattice $L$.
$\mathcal{P}(x)$ The print of the vertex $x$ (see Definition 3.3).
$P$ A print in $Y$ (see Definition 3.13).
$\phi_y$ Local isometry from $\mathcal{Y}$ to $X$ based at $y$ (see eq. (8)).
$q$ Quasi-isometry between $X$ and $\mathcal{X}$.
$R$ Radius such that $Y$ is $R$-locally the same as $X$.
$\rho$ Injective homomorphism from $\text{Isom}(X)$ to $\text{Isom}(\mathcal{X})$.
$r_A$ See Lemma 3.11.
$r_p$ Radius considered to define prints (see Definition 3.13).
$R_X$ Radius such that $\mathcal{Y}$ is $R_X$-locally $\mathcal{X}$.
$r_\mathcal{X}$ Radius such that $t_y$ coincide with $\phi_y$ on $B_y(y, r_\mathcal{X})$ (see page 26).
$r_Y$ See Claim 4.8.
$\tau(x)$ The type of the vertex $x$, where $x$ belongs to the Bruhat-Tits building of $\text{PSL}_n(\mathbb{K})$.
$\mathcal{X}$ The Bruhat-Tits building of $\text{PSL}_n(\mathbb{K})$.
$\mathcal{Y}$ Hybrid graph built to be locally the same as the building (see Section 3.4).
$(y_1, \ldots, y_l)$ A path of adjacent vertices $y_1, y_2, \ldots, y_l$.

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France